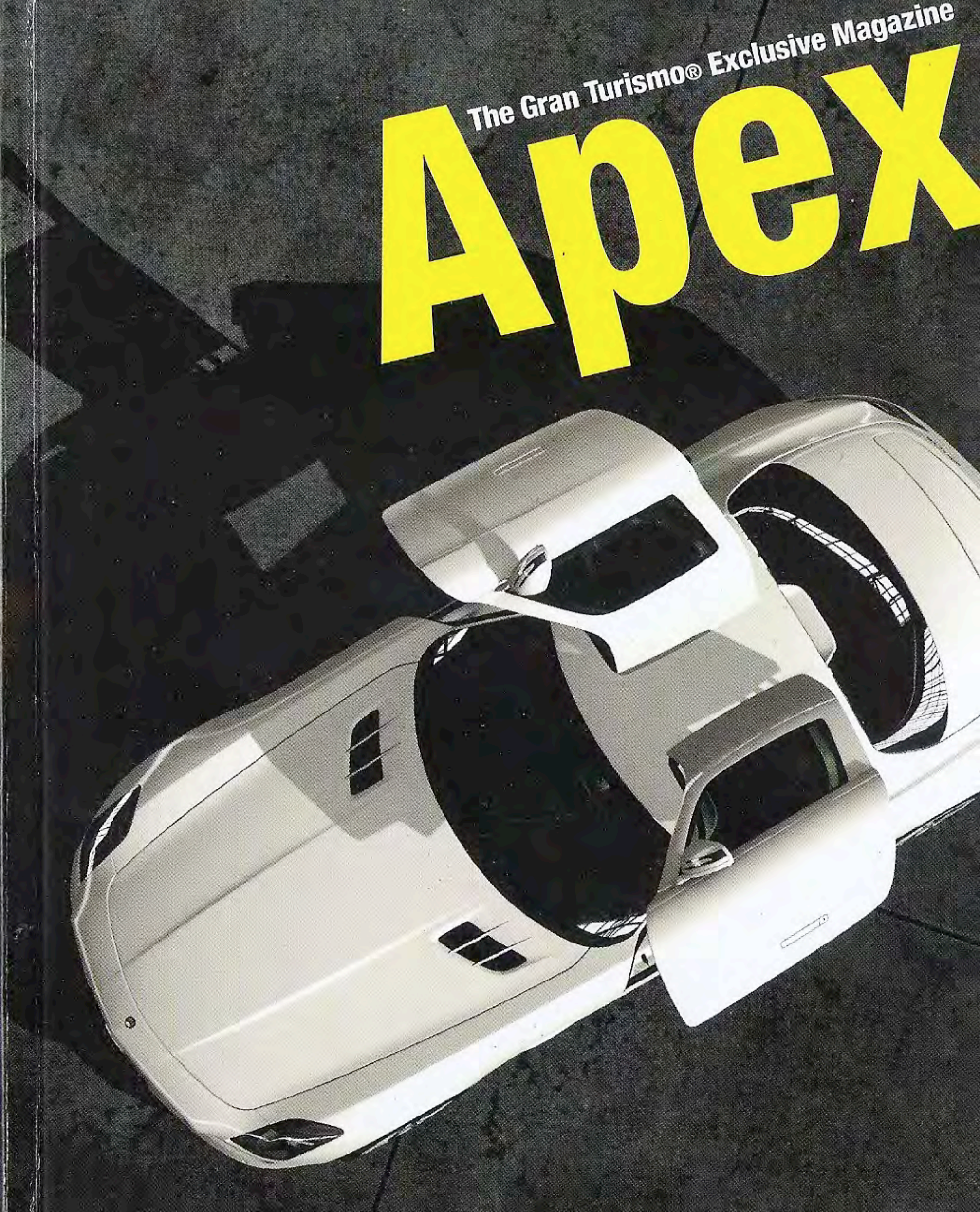
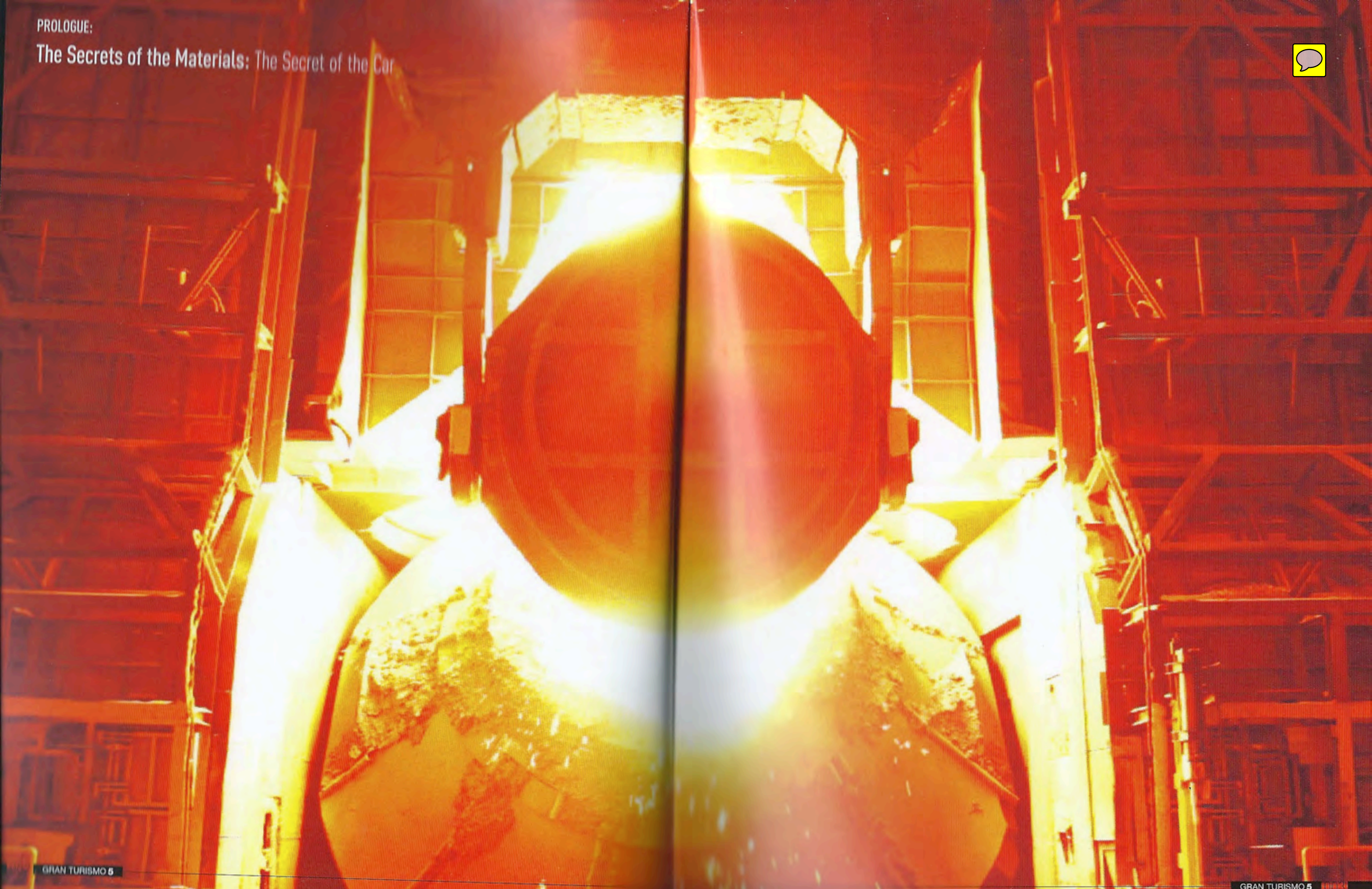
The Gran Turismo® Exclusive Magazine

Apex

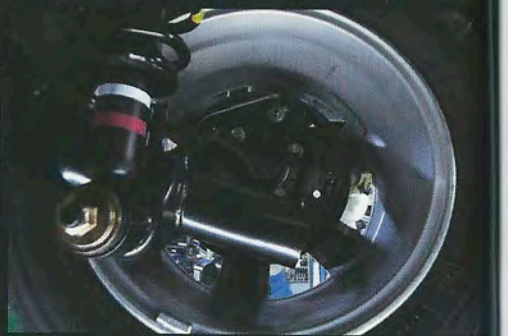


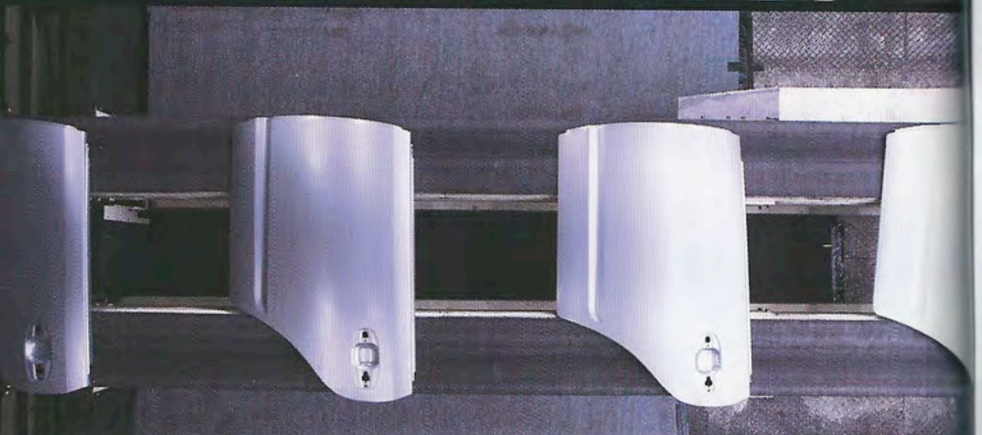
PROLOGUE:

The Secrets of the Materials: The Secret of the Car



In iron-working, iron ore – rock made up of oxidised iron – is harvested and then reduced to pure iron.





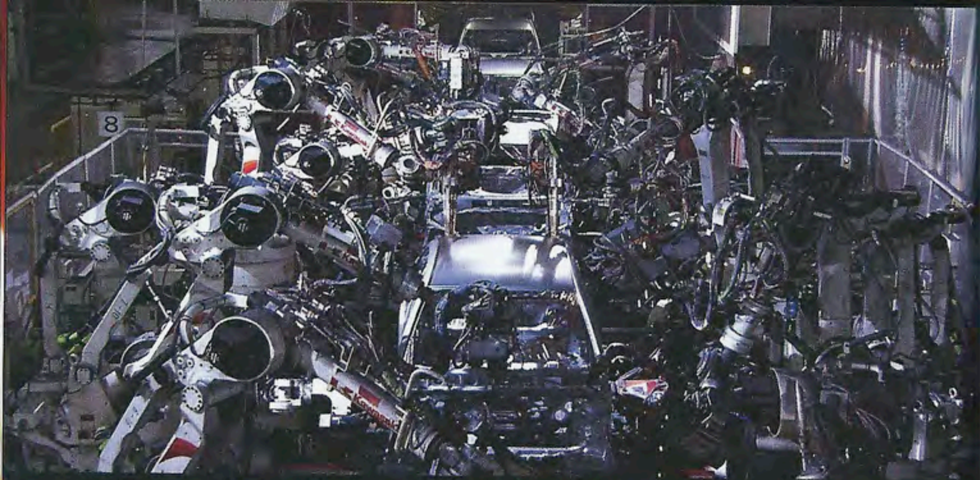
What Is the Secret of the Materials?

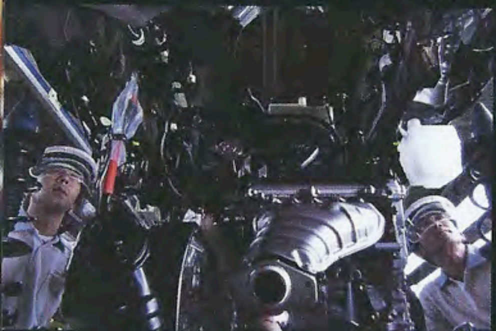
It's all a matter of ingredients, method, conditions, processing and timing. A car is made up of around 30,000 components composed of iron, non-ferrous metals, glass, resin and rubber.

The iron and other non-ferrous metals were made billions of years ago, before our sun was created, perhaps when a star collapsed in a distant corner of some far-off galaxy. Helium is created by the nuclear fusion of hydrogen inside stars, but when the hydrogen is exhausted the helium also undergoes nuclear fusion, producing oxygen and carbon. According to the latest theories, certain stars contract when this happens and their core temperature increases. When it reaches 700,000,000°C, nuclear fusion of the carbon creates neon, aluminium and magnesium, and when it reaches 3,000,000,000°C, the neon gives rise to silicon, sulphur, argon, calcium and titanium. Then finally, at 5,000,000,000°C, iron is born. Iron does not undergo nuclear fusion, and is therefore the ultimate result of this chain reaction.

The explosion caused by a supernova throws out 26 types of matter into space as high temperature gases, and it is from this cocktail of gases that our sun was born. When the Earth was created, iron sank deep beneath the surface to form the core, but the lighter, non-ferrous elements such as aluminium, magnesium and silicon stayed "floating" on the surface, where they hardened. The meteorites that constantly fell to Earth during this time also brought iron to the planet's surface. The layer of silicon coating the surface was gradually worn away, eventually forming sand, while the iron and non-ferrous metals oxidised, forming deposits of rock.

Iron-working is the process of collecting this rock and removing the oxygen to create pure iron. Iron that contains carbon is known as steel, and makes up more than 70% of a car's components. The steel used to create the body panels is flattened into sheets, or "cold-rolled" using huge rollers.





Engine parts and gears that require high strength and durability are produced to the exact form and dimension required by processing alloys made with various other elements, including carbon, vanadium and molybdenum, and using a number of methods. These include casting, where the metal is melted, reformed and then cooled; forging, where the metal is heated and beaten into shape; form rolling, where pressure is used to form the metal into a shape; and machine tooling, where the metal is cut into shape using a blade spinning at high speed.

Aluminium is created by separating out aluminium oxide from an ore called bauxite, and then using an electrolytic refining process to extract the metal itself. Around 8% of a car is made up of lightweight aluminium alloys, which are mainly used for the engine and transmission casings, parts of the subframe and the suspension arms. As well as casting and forging, die-casting, where the molten metal is injected at high pressure into a mould to create thinner parts, is also commonly used.

Silica sand is the white sand found in the desert, and when melted at 2,200°C it creates the transparent material we know as glass. Materials from the living world are also used to create components for these high-tech machines. For example, the rubber used to make tyres comes partly from a rubber tree. This rubber is then combined with oil made up of hydrocarbons to improve upon its natural characteristics and get the best of both worlds.

Interior parts, exterior parts, noise-reducing materials, seals, hoses, pipes and tyres – a considerable proportion of a car is made from rubber and resin. All of these resources were inherited from nature, from the universe and our planet, but without mankind they would have remained unused and unvalued. The secret of the car is the distillation of human resourcefulness – it is human ingenuity in crystallised form.

Rei-ichiro Fukuno

Mr. Rei-ichiro Fukuno is an automotive journalist who specialises in automotive history, production technology, motion dynamics and car restoration. His automotive credentials are backed up by his vast knowledge and precise research on the subject. This knowledge, matched with his crisp writing style, has earned him many followers. He is also deeply familiar with military topics.

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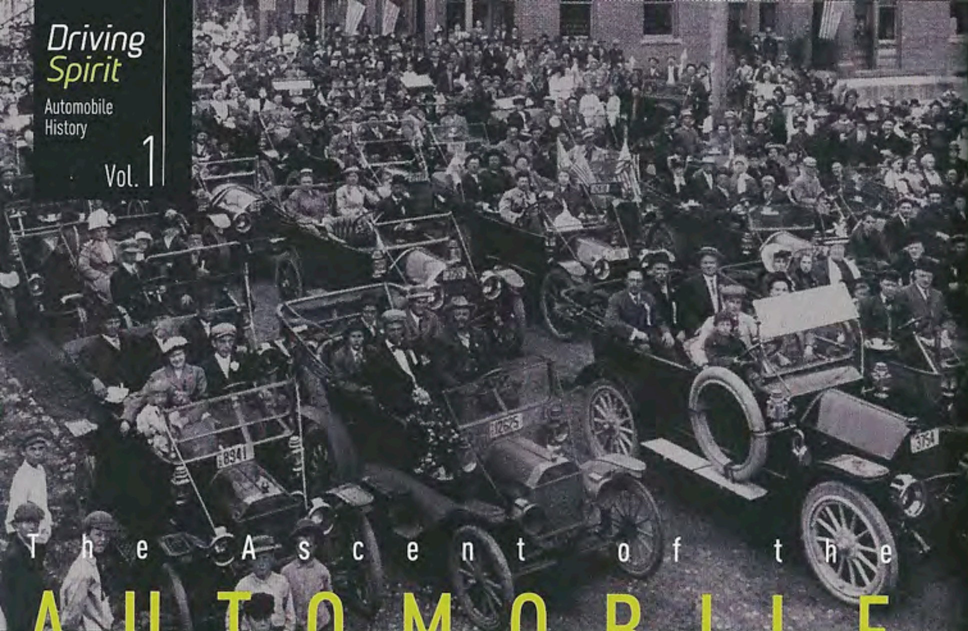


The Ascent of the AUTOMOBILE

From the Invention of the Wheel to the Electric Car

Let's start by turning the clock back by more than a century. Karl Benz applies to have a new patent registered at the German Imperial Patent Office, and the modern automobile is born. Since then, the development of the petrol-powered automobile has followed a course beyond the wildest dreams of its pioneers. Driven on by the inventions and innovation of countless engineers, the history of the modern automobile has taken all manner of twists and turns. Let's take a closer look at how it all unfolded.

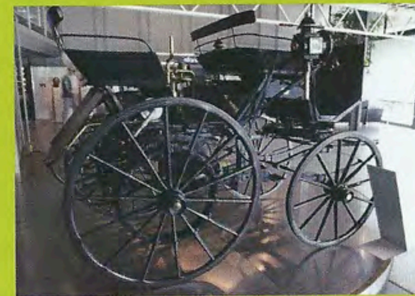
Tracing the Roots of One of the Century's Most Significant Inventions

From Steam Power to the Internal Combustion Engine

The first element of the modern automobile created by man was the wheel. It is said that man first invented the wheel in 3,500 BC in the vicinity of the Black Sea, when it was used for carts pulled by horses and cows. The horse-drawn cart in particular played an important role in human transportation right through to the early twentieth century due its speed and comfort.

When the Industrial Revolution began in Britain in the 18th Century, a new source of power came to people's attention. This was the steam engine, which utilised the boiling and cooling of water for propulsion. Vehicles were fitted with steam engines in the 1820s, and in cities like London, steam-powered passenger buses began to appear on the streets. At that time however, the potential benefits of the automobile were still not fully grasped. The most extreme example of the failure to realise this potential was the enactment of the Red Flag Act in Britain in 1865. This made it compulsory for someone to walk ahead of each automobile holding a red flag, in order to prevent them from scaring horses or carriage drivers. Essentially, this law meant that automobiles were forbidden to travel faster than walking pace. The Red Flag Act served to hinder the development of the automobile in the UK, and resulted in it falling behind other countries.

Meanwhile, in the United States and mainland Europe, the steam engine was joined by the invention of the electric motor and petrol-powered engine, allowing automobile development to progress in leaps and bounds. The German inventor Nikolaus Otto created the first four-stroke internal-combustion engine in 1861.



The four-wheeled automobile created by the German industrialist Gottlieb Daimler in 1886. It was known as the "motor carriage".

The four strokes used by the Otto Engine were intake, compression, power and exhaust – less scientifically known as "suck, squeeze, bang and blow". It was this incredibly efficient invention that led to explosive growth in the popularity of the petrol powered engine.

Because of this growth, by 1900, vehicles powered by steam, electric motors and petrol were all competing to prove themselves the most efficient, but in 1901, when vast reserves of oil were discovered in Texas, it was the beginning of the end for the other competitors. As soon as cheap petrol became widely available, most engineers focused their efforts on developing superior petrol-powered automobiles, and the curtain was raised on the era of the internal combustion engine.

There are a number of competing theories concerning who invented the very first petrol-powered automobile, but the most plausible candidate is Karl Benz with his three-wheeled *Motorwagen*. Steering was achieved by means of a stick known as a "tiller" which controlled the front wheels. Benz's automobile could travel at speeds of 15km/h.

Automobile History

The Dawn

1900⇨1930

Looking back on the history of the petrol-powered automobile, there are three engineers whose contributions were fundamental. They are Gottlieb Daimler, Wilhelm Maybach and Karl Benz. In 1886, Benz registered the patent for the petrol-propelled motor vehicle, a three-wheeled automobile known as the Benz Patent Motorwagen. By coincidence, Gottlieb Daimler and Wilhelm Maybach completed their Daimler Motor Carriage in 1886, the same year Benz had his patent registered. It was the creation of these two vehicles that kick-started the history of the petrol-powered automobile.

The Beginning of the Automotive Era

By the 1920s, automobile races began to be held, and these early motor sports events precipitated a rapid evolution in automotive technology. Competing in those races were manufacturers such as Alfa Romeo, Bugatti and Bentley. For example, the Alfa Romeo 6C 1750 Gran Sport raced in the Mille Miglia, a celebrated race that took place on public highways in Italy. Bentley also notably notched up four consecutive victories in the 24 Hours of Le Mans race from 1927 onward.

The Alfa Romeo 6 C 1750 Gran Sport, seen at the time as the pinnacle of Italian sports cars, was designed by the genius Vittorio Jano. His straight six-cylinder engine, fitted with a supercharger, produced what was, at the time, a miraculous 85 horsepower.

Mass-Production and the Birth of the Popular Automobile

Henry Ford established the Ford Motor Company in the USA in 1903. Up until that point, cars had been individually hand-built, and were an extremely exclusive and expensive form of transportation, but Ford succeeded in introducing the conveyor belt manufacturing system, and was able to bring motor vehicles to the masses. By 1927, the number of Model T automobiles Ford had manufactured reached fifteen million, making it by far the world's best-selling car.

By the 1930s, even in Europe, the birthplace of the hand-built automobile, people were clamouring for mass-produced cars like the Model T. The Fiat 500 was introduced in Italy, while in Germany, Ferdinand Porsche created a prototype for the Volkswagen.

This automotive wave also washed up on the shores of Japan. Inspired by the developments in Europe and the US, the Japanese government supported the establishment of a series of automobile manufacturers - including the companies now known as Nissan and Toyota - and for the first time cars were manufactured entirely domestically.

The first large car manufactured in Japan was made by Toyota. Its elegant design, featuring double doors on both sides, was modelled on the DeSoto Airflow model manufactured by Chrysler. Its 3.4 litre six-cylinder engine gave it an output of 65 horsepower.

Historic Changes in Car Design

At first, cars were viewed merely as a development of the horse-drawn carriage - they were even termed "horseless carriages" - and their boxy design reflected this. Then, as motor sports grew in popularity, designs changed in order to improve such essential race-winning characteristics as aerodynamics. In post-Second-World-War America, body designs began to change to reflect the latest fashions, and at the same time, the size of the cars themselves increased. Ultimately, car designers have settled on simple, organic shapes that offer little air resistance.

Pre-1900

Automobiles in this era were modelled on horse-drawn carriages.

1886 – The Daimler Motor Carriage still strongly resembled a horse-drawn carriage.

1900–1930s

Cars took on a distinctive form that emphasised functionality

1914 – The Model-T Ford was starting to resemble the car design we are familiar with today, with innovations including the front-mounted engine.

1930s-1950s

Cars at this time had a dynamic, streamlined design which emphasised their speed.

1934 - The 1934 DeSoto Airflow was seen as the first car to feature a fluid, streamlined body design.

1950s-1960s

The era of the tailfin set new aesthetic standards for cars.

1959 – The Cadillac Eldorado Biarritz came equipped with a set of stylish tailfins.

1960s-1980s

The era of modern car design.

1974 – The BMW 2002 Turbo had thin poles supporting the roof, and a simple design with a very modern feel.

1980s Onwards

The era of aerodynamic, organic design.

1989 – The Audi Coupe Quattro features a perfect balance between practicality and the power of a sports car.

Automobile History

Human Endeavour 1940⇨1960

Propels the Automobile into an Era of Extraordinary Innovation

Lamborghini Countach

Porsche 356

Jaguar E-Type

Ferrari Daytona

Toyota 2000GT

The Toyota 2000GT showed that Japanese automotive technology was on a par with that of the global leaders in the industry. Its straight six-cylinder engine gave it an output of 150 horsepower and, in its day, it was at the cutting edge of motor manufacturing.

Rising from the Ashes of War

As the Second World War came to an end in 1945, America and the victorious nations in Europe began a period of extraordinary innovation in automotive development. At the same time, the car began to be seen as more of a consumer item. The era of mass consumption had arrived in the US, and this served to accelerate this trend in the automotive world. A bigger-is-better approach to body design was eagerly embraced, and tailfins resembling those of aircraft were employed to give cars a futuristic look.

In war-ravaged Europe, the luxury cars that had existed prior to the outbreak of hostilities were no longer to be seen on the roads. In their place appeared a smaller, more practical type of car.

The rebirth of the German car industry was symbolised by the establishment of a new car manufacturer in 1947. Porsche was set up by the brilliant engineer Ferdinand Porsche and his son, Ferry. Ferry Porsche created the 356, basing its design on the Volkswagen Type 1. The 356 went on to set the benchmark for European compact sports cars.

The revival of motor sports gave impetus to sports car manufacturers such as Ferrari, Alfa Romeo and Jaguar, who developed many new models, and road-going racers enjoyed huge exposure during this period.

The Rapid Development of Japanese Cars

A decade had passed since the end of the Second World War, and the automobile industry in Europe had regained its former vim and vigour. This rebirth was perfectly symbolised by the emergence onto the world stage of what would later become known as "supercars". Lamborghini's debut model, the 350GT, was unveiled in 1964, and this was soon followed by the Miura and the Countach. Meanwhile, Ferrari competed fiercely with their rival, releasing the 365GTB/4 Daytona, the BB512 and the Testarossa.

At that time, elegant and refined sports cars were coming to the fore in Britain. The Jaguar E-Type appeared in 1961, with the Aston Martin DB4 and Lotus Europa appearing at the same time. In this era, both sports cars and supercars were reaching a pinnacle of perfection.

It was in this period that Japanese manufacturers began to create cars specifically tailored for the needs of Japanese people. Toyota did not seek to manufacture cars for the foreign market, but looked internally to the domestic market. In 1955, it produced its first Crown cars. It was precisely at this time that the Ministry of International Trade and Industry (MITI) launched their scheme to develop a "People's Car". Although it never became official government policy, the Subaru 360 that appeared in 1958 closely matched the aims of MITI and immediately garnered huge popularity. Then in the 1960s, Honda, who had until then only manufactured motorcycles, unveiled the Honda sports series, featuring the S500, 600 and 800 - and Nissan released the first mass-produced Japanese sports car, the Datsun Fairlady. Toyota then went on to produce the 2000GT. Japan now had ample evidence that in the field of sports cars, its technology was the equal of the global leaders in the industry.

Toyota Publica

Based on the "People's Car Plan" developed by the Japanese Ministry of International Trade and Industry (MITI), this small car took six years to develop. Its interior was spacious enough to allow four adults to travel in comfort, and its air-cooled 700cc OHV two-cylinder engine made long-distance driving possible.

Subaru 360

The monocoque, egg-shaped body represented a revolution in Japanese automobile manufacturing.

Toyota Corolla

A rival to the Nissan Sunny, the Corolla, which launched with a 1.1 litre engine, swiftly became very popular.

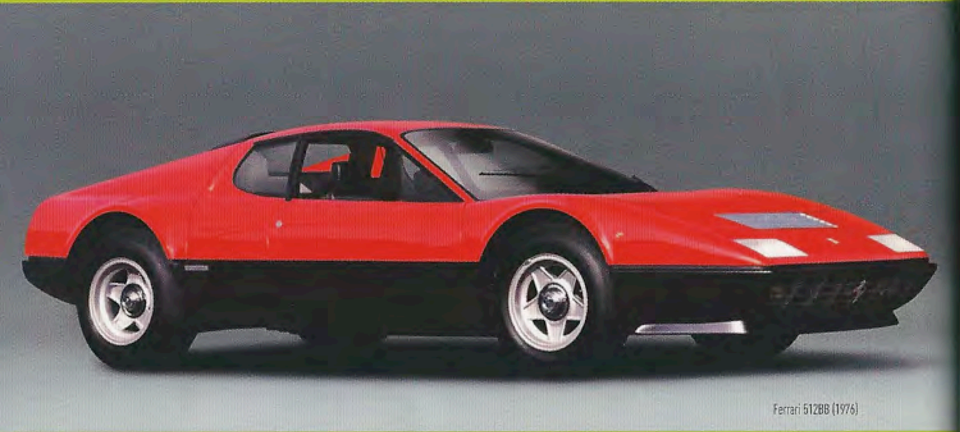
Supercar Design

The mid-engine (or mid-ship engine) layout literally lies at the heart of the supercar. This style of engine layout does not suit a design with a long bonnet, so car designers created vehicles in which the driver's compartment is pushed forward. The development of the Lamborghini from the Miura to the Countach is an example of the evolution of supercars from having long noses to favouring forward-mounted driver's compartments instead.

Automobile History

The Age of Speed

1970⇨1990



Ferrari 512BB (1976)

The Spread of High-Performance Technology

By the 1970s, the application of high-performance technology accelerated, and it was utilised more widely in the mass market. Sports cars in particular benefitted from this trend as until this point sports-car engineering had been generally handled in the same way as that of racing cars, but now sports cars began to mark out their own unique terrain as high-performance vehicles for the consumer market. In the United States, the Clean Air Act (also known as the Muskie Act) and the oil crisis of the early '70s presented challenges to the automobile industry, but this adversity became opportunity with the development of more fuel-efficient and cleaner engines. This of course resulted in more environmentally friendly and efficient cars.

New brands such as the Ford Mustang and the Pontiac Firebird muscled their way into the marketplace, competing with old favourites like the Chevrolet Corvette via increasing levels of performance. In Europe, the supercar had become well-established, and mass-produced sports models that were within the budget of ordinary consumers gained huge popularity.

New models were released by manufacturers including MG and Lotus in Britain and Alfa Romeo in Italy. The spread of high-performance features such as DOHC engines and turbochargers played a major role in boosting the popularity of these cars.

Mazda Savanna RX-7 (SA22C model)

Domestic sports car production in Japan was in the doldrums when this compact, light-weight high-performance sports car burst onto the scene. It came fitted with a rotary engine.

Chevrolet Corvette

The definitive American sports car, the fourth generation of the Chevrolet Corvette, known as the C4, was released in 1984.

In Pursuit of the Sports Car Dream

Nissan R32 GT-R (1989)

Japanese Sports Cars Take the World by Storm

The advances made by the Japanese auto industry was also significant in this era. In Japan during the 1970s, the living standards of Japanese people increased dramatically thanks to a period of rapid economic development, and a wide variety of sports cars with unique designs began to appear. When it was first released in 1978, the Mazda Savanna RX-7, with its streamlined body and rotary engine, was like a breath of fresh air in a domestic sports car market that had stagnated following the oil crises. Development continued on the celebrated Nissan Skyline, while the Fairlady Z (known as the Nissan S30 outside Japan) brought the company global success. The S30 was used in events such as the Safari Rally, and along with the Skyline, it cemented Nissan's position as a major sports car manufacturer.

Toyota unveiled the Supra, a sports car based on their Celica. Combining an FR chassis and six-cylinder engine, the Supra gained widespread popularity and enjoyed huge success on racing circuits. By the end of the 80s, the Honda NSX and Mazda MX-5 (also known as the Eunos Roadster) had achieved global success, and were even influencing the design of US sports cars. The early 1990s then witnessed the birth of the Subaru Impreza and the Mitsubishi Lancer, and thanks to their appearances on rally circuits worldwide, these cars became powerful statements of the advances made in high-performance motoring technology by Japanese manufacturers.

Honda NSX

The first Japanese supercar, the NSX was developed with Honda sparing no expense in applying the technology it had developed in the motor sports field, including Formula One.

BMW M3

In the 1980s, the standard model for touring car racing was the BMW M3 (E30 model), which enjoyed tremendous popularity.

Automobile History

The Present Day

Further Refinement and a Brighter Future

2000 ⇨

Two Trends Born of Innovation

By the 1990s, with developments in the field of electronics, two major new trends could be seen in automotive manufacturing. The first was the search for the successor to the internal combustion engine and the emergence of the next generation of cars. In 1995, Toyota unveiled the Prius, a concept car that combined the internal combustion engine with an electric motor. In 1997, it went into production as the world's first mass-market hybrid car. Honda then introduced their hybrid sports car, the Insight, in 1999. The days when cars had relied entirely on the internal combustion engine were coming to an end. By the early Twenty-First Century, completely electric vehicles (EV) began to be produced, and the options open to manufacturers aiming to create next-generation cars have been steadily increasing ever since.

The other trend was the development of the super sports car. Owing to advances in engine technology, materials and car control features, it had become much simpler to create Twenty-First Century sports cars that boasted specifications far superior to those of older models.

The McLaren F1 road car, released in 1993, is generally seen as having started this trend, and by the twenty-first century, it had been joined by high-profile cars including the Enzo Ferrari, the Porsche Carrera GT and the Mercedes-Benz SLR McLaren. The ultimate example of the super sports car is considered to be the Bugatti Veyron, which went on sale in 2006. It boasts an engine output of up to 1001 metric horsepower and a top speed of 407km/h.

More exciting models have entered this market, including the Audi R8, the Lamborghini Murcielago LP670-4 SV, and the Alfa Romeo 8C Competizione, and interest in super hi-spec sports cars shows no signs of sign of decline.

Tesla Motors – Tesla Roadster

Released in 2008, this electric vehicle shows the way forward for the next generation of sports cars.

Bugatti Veyron

The reigning king of the super sports car world. Its 8 litre 16-cylinder W16 engine can produce an output of 1001 metric horsepower.

Next-Generation Car Design

In the past, a car's design would depend largely on the individual tastes of the designer. However, in recent years, a larger part of the car's design has been determined by functional considerations, such as the need for an aerodynamic shape, or the need to use certain materials. It is now standard to only turn to concerns of beauty and unique character once these issues have been dealt with. Next-generation cars have the potential to revolutionise car design, and cars are soon likely to appear that would have been unimaginable in the era of the internal combustion engine.

CHAPTER

01

Apex [The Gran Turismo® Exclusive Magazine]

Driving Techniques

Controlling Your Car


AMG

The Role of Tyres
CHAPTER 1
Driving Techniques

The Role of Tyres

In this chapter, we'll be looking at how to master driving by focusing on tyres. The first step is to grasp the role that tyres play, as an understanding of how tyres behave is one of the best ways of quickly becoming an accomplished driver.

The Friction that Fixes the Car to the Road

Weight on Tyres = Load

In motorsports, tyre choice can often spell the difference between victory and defeat. No matter what circuit you're racing on, trying to shave a second off your lap time using engine power alone is no easy task. Tyres, on the other hand, have the potential to trim your time by that crucial margin.

Before switching on the ignition, let's take a look at the exterior of your car. A car is made up of thousands of parts, but only the tyres come into contact with the road. This means that they play a huge part in determining how a vehicle handles.

It's vital to remember this fact when thinking about your driving technique. It's no exaggeration to say that successfully driving a car at high speeds comes down to knowing how to fully utilise your tyres. So, as a first step towards total mastery of your vehicle, tyre knowledge is absolutely crucial.

The fact that a car can remain stationary is due to the friction between the tyres and the road. It's also thanks to friction that the car gets power from the engine and is propelled forward. The friction between tyre and road surface is known by a special term: "grip" - this is the strength with which tyres hold onto the surface of the road and prevent slippage.

The most important factor when considering grip is how it changes according to conditions. The simplest example is in rainy conditions: the road is wet, and grip is reduced, causing tyres to slip more. But changes in grip are not all simply due to the road surface. They also have to do with the car itself, with the chief factor being the weight that is put on them.

Since tyres support the whole car, it's obvious that the entire weight of the car rests upon them. If a car is driving up a hill, the weight placed on the front tyres will decrease while the weight on the back tyres will increase. And when braking, the car's body will pitch forward, increasing the weight on the front tyres and decreasing that on the rear.

In this section, we will refer to the weight placed on the tyres as the "load". A tyre's grip is closely related to load. The bigger the load, the stronger the grip - and the lighter the load, the weaker the grip.

Estimated Friction Variation on Different Road Surfaces

Concrete (Dry)	1.0 ~ 0.5
Concrete (Wet)	0.9 ~ 0.4
Asphalt (Dry)	1.0 ~ 0.5
Asphalt (Wet)	0.9 ~ 0.3
Gravel Track	0.6 ~ 0.4
Soft Snow	0.4 ~ 0.35
Hard Compacted Snow	0.3 ~ 0.2
Icy Surface	0.2 ~ 0.1

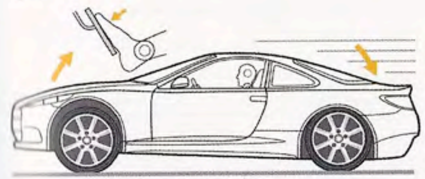
Grip varies

The Load Is Constantly Changing

When you drive a car, the load placed on the tyres varies from moment to moment. When you put your foot down, weight is transferred to the rear of the vehicle, putting a heavier load on the back tyres. This increases the grip of the back tyres and decreases the grip of the front tyres, which means that steering becomes more difficult when a car is accelerating.

Conversely, when the car is braking, the load on the front tyres is increased, meaning that their grip becomes stronger. But by the same token, the rear tyres' grip will decrease, making the car less stable (Fig. 25-1).

Fig. 25-1



When you press the accelerator, the load is shifted to the rear, and when you release it, the load shifts to the front. You can feel these variations in load through the bottom of your foot.

When a car goes into a corner, centrifugal forces act on it, tilting it towards the outside of the bend. This increases the load on the outside tyres, increasing their grip, and decreasing that of the inside tires.

By being aware of these variations in load and utilising them to your advantage, you can improve your driving performance by carefully controlling how the load shifts. Mastering the art of shifting load is the key to a superior driving technique. It's something which will be referred to again and again, so take careful note of it.

Column

Although we've referred to "shifting the load", unless the car is being pushed towards the ground by airflow over its body as in a racing car, the total cumulative load on the four tyres will not change. Think of it as the same weight being distributed in different ways amongst the four tyres. For instance, when the car pitches forward, the load on the front tyres will increase, but the load on the back tyres will also decrease by the same amount.

Get an idea of how grip works

Viewing Grip with a Friction Circle

A Car Won't Turn When It Is Braking Fully

Now let's turn our attention to grip. A single tyre is only in contact with the surface of the road in one spot. In that contact area, a tyre is gripping in the front-rear and left-right directions.

Looking at it from an operational perspective, grip in the front and rear direction is affected by accelerating and braking operations, and grip to the left and right is affected by steering operations that turn the car. This may lead you to believe that forward-rear and left-right grip are separate things, but that would be a wrong assumption. A tyre's grip is not divided into front, back, left and right. It is simply a case of gripping force being distributed differently. If you slam your foot on the brake, all of the grip will be used to slow the car, meaning that there is no grip left to apply to turning left or right. So even if you turn the steering wheel, the car will be unable to turn in response. The friction circle is a simple way of showing the status of a tyre's grip. It is a diagram in which the maximum grip of the tyres is shown as a circle.

Picture a car going around a corner. The operation is described in more detail from page 34 onward, but basically it's a process of braking, turning the steering wheel into the turn and then turning the steering back while accelerating out of the turn. In the initial braking, all of the gripping capacity of the tyre is used in the longitudinal (forward-aft) direction in order to decelerate in the shortest distance possible. That is to say, even if you attempt to steer, there won't be enough gripping force remaining to use in the left or right directions and the car will not turn. When cornering, the basic rule of thumb is to complete braking before turning/steering the car. If you look at the friction circle, the reason for this should become clear (Fig. 27-1).

When accelerating out in the latter half of a corner, the steering wheel is gradually straightened while giving more and more throttle. This is because you are reducing the amount of grip being used to turn the car, and making room for gripping force to move the car forward. (Fig. 27-2). In an ideal cornering manoeuvre, you would use the gripping force in a manner which traces the perimeter of this friction circle, i.e. at the limit of the overall tyre grip, balancing between longitudinal (acceleration/deceleration) and lateral (cornering) grip. Being able to picture clearly both the friction circle and the tyres' grip condition while cornering will lead to a drastic improvement in your driving.

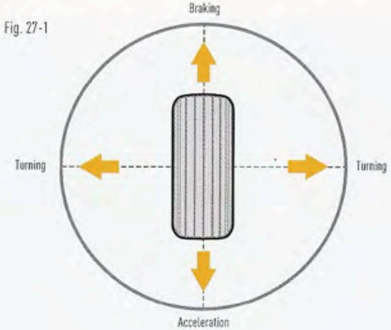
Using the Whole Body as a Sensor

When you're driving, a whole range of things besides the friction circle demands your attention - the steering wheel, the accelerator, the brake pedal and sometimes even the feedback from your seat.

For instance, understeering (→p. 38) occurs when a car doesn't turn to the same extent that the driver is turning the steering wheel. It's possible for a driver to detect gradually increasing understeer by the way that the steering wheel starts to feel lighter. At this stage, the driver can still prevent the car from straying from its intended path by making small adjustments.

A driver should also be able to sense when the performance of their tyres is deteriorating. As tyres are worn down by driving around the circuit, they become less responsive and react less quickly to the driver's input. In addition, during extended periods of driving the air pressure in the tyres can get too high, and the driver will begin to feel any bumps in the road more keenly than before.

Fig. 27-1



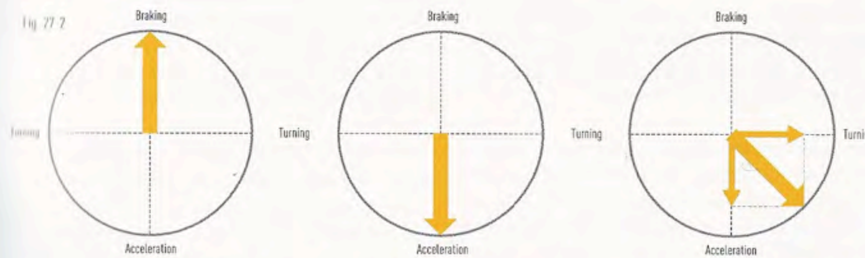
The friction circle is a graphical representation of a tyre's grip. The circle marks the limit of the tyre's grip and the four directions represent acceleration, braking and turning.

Column

We've shown the friction circle as a perfect circle here, but in actuality a tyre's potential for gripping varies between the lateral directions (for cornering) and longitudinal directions (for braking or accelerating). Therefore a real friction circle will not be a perfect circle, it will be an ellipse.

With tyres designed for the general motorist, braking power is generally emphasised, which means that friction "circles" are often in fact vertically oblong in shape.

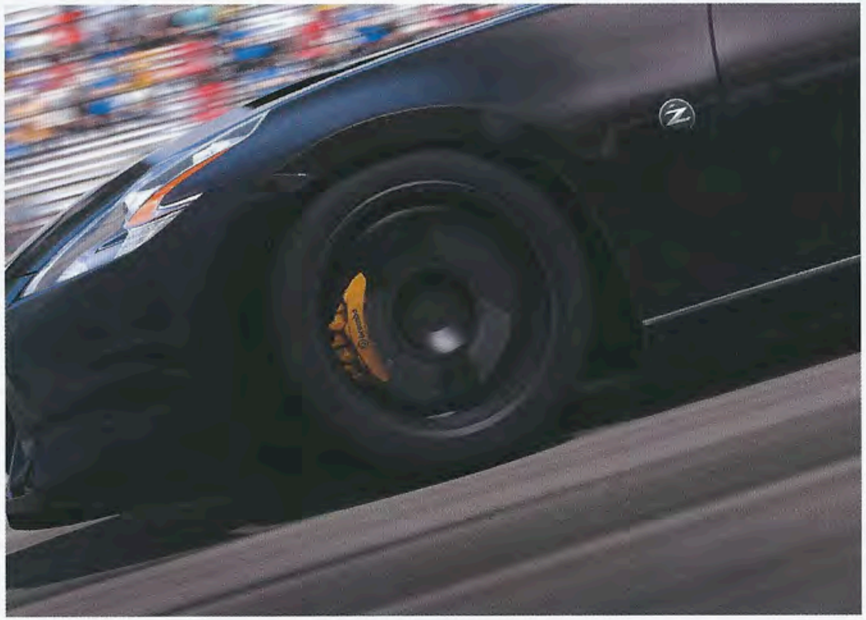
Fig. 27-2



This is how the friction circle represents a tyre's grip when the brakes are fully applied. The tyre's grip is being used entirely for braking, which means that there is no grip available for turning the car.

The friction circle when the vehicle is accelerating rapidly. As all the grip is being used for acceleration, even if the driver turns the steering wheel, the car won't turn.

The ideal friction circle when accelerating out of a curve. At the limit of the tyre's grip, the grip is nicely balanced between turning and acceleration.



Tyres Are Constantly Slipping

The Ideal Tyre Slip Percentage is 10-15%

Let's continue our discussion of tyre behaviour by taking a look at what's happening in detail. Racing car tyres boast high grip, but this doesn't mean that they firmly grip the road surface like two cogs meshing. In reality, grip is created by the action of tyres slipping incrementally on the road.

When an unnecessarily large amount of engine power is transferred to the tyres, they will screech and skid on the road's surface. This is known as wheelspin. Slip ratio is a numerical indication of the degree to which tyres slip. If a tyre with a circumference of two metres completes a single revolution and the car travels forward two metres, the tires have a slip ratio of zero. However, if they only produce one metre of forward movement, they have a slip ratio of 50%.

In other words, tyre slippage in this case has meant that the car has only travelled forward by half the circumference of the tyres (Fig. 29-1).

In order for the tyres to exhibit the highest level of grip, studies have shown that the optimum slip ratio is somewhere between 10% and 15%. This is not something that is easy for an inexperienced driver to sense using their body. It's easiest to remember that tyres start to squeal slightly when their grip is at its strongest. If the slip ratio rises above 15%, grip will steadily decrease.

The above is in regards to the slip ratio of tyres in the longitudinal, front-aft direction, but as explained before, grip also acts in the same way in a lateral direction. This means that during cornering, a slip ratio of 10-15% is when the tyres are providing maximum grip. Again, the sound of the tyres squealing can be used to gauge the current slip ratio. Always remember that the fastest cornering can be achieved when the tyres are slightly squealing.

A Car Won't Be Turned By the Steering Wheel Alone

Finally, let's consider the slip ratio of the front tyres, which determine the direction in which the car travels. Turning the steering wheel causes the front wheels to move. There's a tendency to assume that the car will travel in the direction that the front wheels are pointing, but this is not the case. Take a look at the front tyres when a car is cornering and you'll see that the angle at which the car is turning is not as great as the angle of the front wheels. The difference between the direction in which the wheels are pointing and the direction in which the car actually travels is known as the "slip angle" (Fig. 29-2).

This slip angle is related to the tyres' grip. The slip angle at which grip is greatest is 8-10 degrees; if it gets any larger than this, grip will decrease. So beyond a certain angle, no matter how much further the driver turns the steering wheel, the car will not turn any harder.

It's important not to get the slip angle confused with the angle of the steering. The slip angle varies depending on speed and the load placed on the front tyres, and is not determined by the angle of the steering wheel alone. This is also something that's hard for a novice driver to get a feel for, but a good indicator is the squeal of the front tyres while the car is in motion. You'll eventually learn to gauge when the car will not turn any more even if you turn the steering wheel harder, from the sound coming from the front tyres.

Now let's turn to a more detailed discussion of car control.

Fig. 29-1

Tyres with a circumference of one metre, travelling forward one metre without turning at all = slip ratio of 100% (locked wheels)

Tyres with a circumference of one metre, travelling forward one metre during one half-turn of the wheel = Slip ratio of 50%

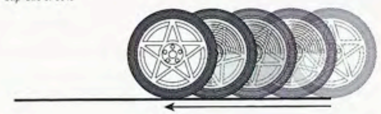
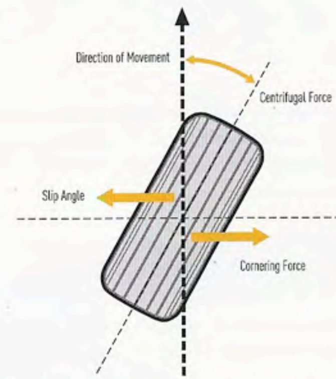


Fig. 29-2



When a car corners, it does not travel at as large an angle as the angle in which the tyres are turned. The difference between the steering angle and the actual direction of travel is known as the slip angle. A slip angle of about 10 degrees will give a tyre its maximum cornering force.

The car does not turn as much as the angle of the wheels

Starting & Stopping
CHAPTER 1
Driving Techniques

Starting & Stopping

Let's begin our look at how to control a car with a discussion of the techniques used for accelerating from a standstill and stopping a car. Learn to perform optimum starts off the line and controlled braking that will fully utilise the grip of the tyres.

Perfect Acceleration from a Standstill

Releasing the Clutch All at Once

Now that you've grasped the importance of the tyres, let's actually get behind the wheel of the car and accelerate off the line. For day-to-day driving, the car should be started as smoothly as possible, but when it comes to sports driving, where you are competing for speed, the priority is to effectively transfer as much of the engine power as possible to the road surface, even if it entails some degree of turbulence.

We will start by discussing what happens when accelerating in a car with manual transmission. The key point to focus on is the instant when the car starts moving. What you want to do is to transfer all of the engine power to the tyres, to gain maximum propulsion.

The driver must find the optimum RPM for the engine and engage the clutch instantly at that RPM. With manual transmission, you connect and disconnect the transfer of engine power with the clutch, but if you are slow to do so you will lose valuable power and time. The key is to press the accelerator pedal while monitoring the rev counter and release the clutch all at once.

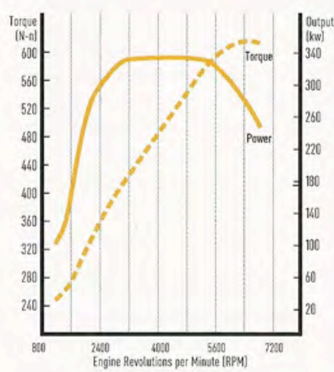
The optimum engine RPM for engaging the clutch in this manner can be found by looking at the RPM range where the maximum torque is produced. Find this figure in the performance spec of the car and engage the clutch at 500RPM's higher than where the maximum torque is produced. If the tyres do not slip and you do not hear them screeching at all, you can try engaging the clutch at a slightly higher RPM. If the tyres smoke and continue to screech after launching, lower the RPM where you engage the clutch. By experimenting like this, you want to find the point where the previously mentioned slip ratio is 10-15%, where your tyres will be producing the maximum grip (Fig.30-1).

Once you've got your vehicle off to a good start, the next step is to continue to accelerate without interruption. Floor the accelerator and rev the engine until the rev counter is just up to the red zone. As soon as the engine reaches the red zone, step on the clutch and change gear quickly, then engage the clutch again. You want to be able to repeat this quickly as possible.

Many modern cars come fitted with electronic management systems such as traction control and stability control, in order to improve the stability of the vehicle (→p.112). These systems can detect tyre slippage and sometimes suppress the engine's power, which may prevent you from gaining the optimum grip from your tyres. In this case, try switching these electronic devices off.

Rapid advances have been made in these electronic systems in recent years and their benefits should not be ignored for sports driving, but being able to control the car on your own will be a shortcut to improving your driving skill.

Fig. 30-1



An example of an output graph showing engine power (the solid line on the graph) and torque (the broken line on the graph). In this graph, maximum torque is achieved at around 3200-5600 rpm. This zone is known as the "torque band".

Transferring power directly to the road

The Rise of Semi-Automatic Transmission

In recent years, more and more high-powered sports cars have been fitted with new types of automatic transmission that allow quicker gear changes than manual transmission. These new types of transmissions, the most prominent being the Dual Clutch Transmission (DCT) (see column), eliminate the clutch pedal and allows easy automatic gear changes, as well as manual changes using paddles or buttons on the steering wheel. In high-powered cars such as those that exceed 500 horsepower, the revs in first and second gear can jump instantly into the red zone, forcing the driver to be extremely quick on the clutch. Freeing the driver from this operation brings great advantages in terms of sports driving.

Column

Dual Clutch Transmission (DCT) can be seen in sportscars such as the Mitsubishi Lancer Evolution X and the Nissan GT-R. The DSG (direct shift gearbox→p.117) of Volkswagen is also the same type of mechanism. It allows an almost uninterrupted transfer of engine power to the wheels. The effective time lag for gear shifts is minimised, and the reduced stress to the engine makes it ideally suited to motor sports. It is predicted that this type of transmission will become standard in sports cars hereafter.

Creating stopping power

Stopping at a Desired Spot

Listening for the Screeching of the Tyres as a Guide

Once you've mastered the art of getting off to a flying start, the next skill to master is stopping your car. It's time to take a closer look at braking. You might think braking is fairly straightforward – you step on the brake and the car comes to a halt - but there's actually much more to it than that. Slowing your vehicle down in precisely the way you intend demands real precision and control.

Again, the first issue that requires consideration is the slip ratio of the tyres. The most efficient way to bring your car to a halt is with a slip ratio of 10-15%, just as for optimum acceleration. To put it in more concrete terms, maximum braking power is achieved at the point when the brake pedal is pressed just enough for the tyres to begin to screech (although there are some racetracks with high surface friction on which tyres will not screech).

Some drivers may worry about locking the wheels when braking, and so choose to press the brake down gradually, but in motorsports this is the wrong approach. The best technique is to step quickly on the brake pedal with enough force to potentially cause the wheels to lock. If the wheels do lock, release the brakes just a little to achieve the ideal slip ratio. If you can control the brakes in this manner you are probably an advanced driver. (Fig. 33-1).

When you're tearing down the home straight into the first corner and need to brake rapidly, it's vital to learn how to judge the correct point at which to step on the brake. There are usually signs on the track to indicate the distance to the corner, so make full use of these. On tracks where there are no signs, use roadside objects and structures to gauge the distance to the corner.

Braking Changes Depending on Car Layout

The vast majority of cars are now fitted with anti-lock braking systems (ABS), so in many cases the techniques discussed above will be performed automatically. However, there are cases where the required distance for braking will become longer depending on the slipperiness of the road surface or even the performance level of the ABS system, and it still pays to learn how to manually control your car's braking.

Another factor influencing braking is the layout of the car (→p.79). The rear tyres are responsible for maintaining the car's stability, but when braking the car pitches forward, reducing the load on the rear of the car. This lowers the grip of the rear tyres, making it difficult to fully utilise the maximum grip of all four wheels for braking (Fig. 33-2).

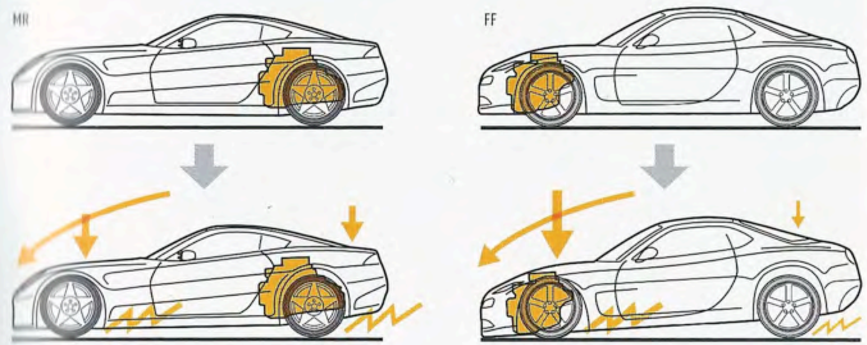
That is why in terms of braking, a drivetrain layout of a car where there is more weight towards the rear has an advantage. This means that an RR (rear engine, rear wheel drive) layout or mid-engine (also known as mid-ship engine) layout for a car allows stronger, more stable braking. Conversely, when heavy parts are mounted in the front of the vehicle in FF (front-engine, front-wheel drive) layouts, braking can reduce stability and cause excessively large movements of the car's body.

It is however also possible to make use of the instability that braking can cause in order to corner more effectively. We will go on to discuss this technique for improved cornering on the next page.

Fig. 33-1

Step on the brake pedal as rapidly as you can, as if to lock the wheels.

Fig. 33-2 A comparison of the braking load of MR (mid-engine, rear-wheel drive) and FF (front-engine, front-wheel drive) layouts (see p.79 for a detailed look at different car layouts). MR layouts place the engine in the middle of the vehicle's body and allow the grip of all four tyres to be used effectively for braking. In contrast, FF layouts exert an excessive load on the front tyres and the grip of the rear tyres tends to be reduced.



The Basics of Cornering

CHAPTER 1
Driving Techniques

Cornering Basics

Brake, turn and accelerate. Cornering requires a combination of steering and pedal control. Let's go through the basics.

Steering and Using the Pedals

The Three Stages of Cornering

Now let's look at cornering, a skill that combines both steering and pedal control. This was touched upon in the section about the friction circle, but when cornering, grip should be utilised in the order of deceleration, turning, and acceleration. Linking together braking, steering and acceleration in a smooth, flowing movement is the key to fast cornering. Now let's divide the cornering process into its three component parts [Fig. 34-1].

The first thing to consider is how to brake as you approach a turn. If you're coming towards a corner at full speed on a straight section of the track, you will need to slow down as quickly as possible to the fastest speed that will allow you to successfully negotiate the corner. Aim to brake swift and hard, as discussed earlier. The "fastest speed" here refers to the fastest possible speed at which the car can be controlled and driven as intended, even at the point on the corner where the centrifugal force is at its strongest (this is usually the point where the steering wheel will be turned at the greatest angle).

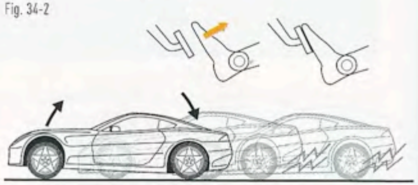
Once you have slowed down to the highest speed at which you can take the corner, the next step is to steer. Take your foot off the brake pedal to free up some of the grip that was being used for braking. Turn the steering wheel, and the grip you have freed will be transferred into making the car turn.

What you really want to avoid when turning into the corner, is sudden, violent movements with the steering wheel. As discussed in the section on slip ratios, even if you make a sharp turn on the steering wheel and turn the front wheels rapidly, this will not necessarily result in making the car turn as desired. The steering must be operated gradually in consideration for the grip of the tyres [Fig. 34-2].

Fig. 34-1

If you move the steer too much while cornering, you will not be able to maximise the grip of the tyres. in the diagram, imagine cornering as being divided into three stages: braking, turning and acceleration.

Fig. 34-2



Always remember the changes of loads on a car in response to acceleration and braking. If you steer without consideration for the operation of the pedals, the car will not move as intended.

Transforming vertical grip into lateral grip

Accelerate as You Return the Steering Wheel

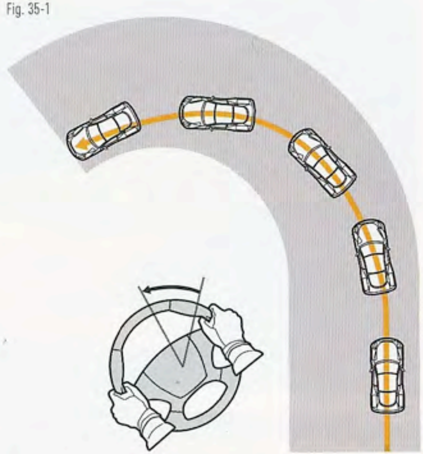
When a car is turning, it is overcoming centrifugal force in order to continue to turn. The ideal speed for cornering is the speed at which the tyres are just beginning to squeal.

At this point, the grip of the tyres is being used to turn the car, so it is important to carefully control the forward propulsion acting on the vehicle – in other words, you need to operate the accelerator pedal with care. Specifically, you need to operate the accelerator pedal so that you do not accelerate or decelerate until the corner exit. You must maintain partial acceleration.

As soon as you see the exit of the corner, you should steadily straighten the steering wheel, reducing the centrifugal force acting on the car. This frees up some of the tyres' grip, which can then be transferred into increasing the car's speed, allowing you to accelerate quickly out of the corner.

As you come out of the corner, it's finally time to gradually give it full throttle. The sooner you do this, the better, but if you floor the accelerator before the car has fully come out of the corner, it could make it difficult to complete the turn. The key to speeding out of a corner is to steadily straighten the steering wheel while increasing the amount of acceleration at the same time [Fig. 35-1].

Fig. 35-1



When cornering, aim to keep the steering wheel at a steady angle. If you move the steer too much while cornering, you will not be able to maximise the grip of the tyres.

Tricks for reducing centrifugal force

Taking the Right Racing Line When Cornering

Faster Cornering with the Outside-Inside-Outside Racing Line

In the last section, we looked at cornering controls. Next, let's take a look at the best line to take when cornering.

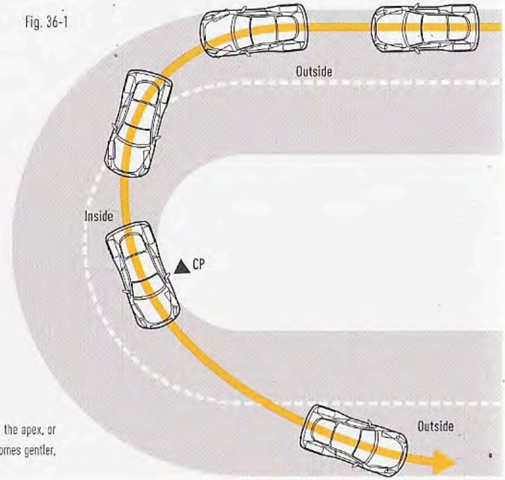
The basic path or line to aim for when cornering runs from the outside of the track, to the inside, to the outside again. This means that as you enter the corner, you should position the car at the outer side of the track. You should then turn in and pass through the inside part of the track as you turn the corner, before moving back to the outer side of the track again as you exit. By driving around the corner at a shallower angle than the entire shape of the corner, you can drive through at higher speeds. This allows you to increase the throttle early on when accelerating out of the corner [Fig. 36-1].

Cast your mind back to the centrifugal force mentioned in the last section. When a car corners, centrifugal force acts on the car to push it towards the outer edge of the track. This force increases as the corner becomes tighter, or as the car's speed increases.

In other words, assuming that the grip of the tyres remains constant, the wider the corner arc, the lower the centrifugal force - allowing the car to move through the corner at higher speed. This means that you can increase the speed at which you drive around a corner by driving at the widest angle possible using the entire width of the track.

However, there are exceptions to this rule. The drawback of using this out-in-out technique is that it increases the distance you travel. When negotiating an extremely large corner, or when the power of your car is much less than the tyres' grip, it can be faster to stay on the inside of the track at all stages of the corner.

Fig. 36-1



The optimum outside-inside-outside line to take when cornering. By positioning the apex, or clipping point closer toward the exit of the corner, the second half of the turn becomes gentler, and the area from where you can accelerate can be made longer.

Positioning the Clipping Point

When cornering, the point at which the path of the car driving through a corner is closest to the inside of the curve is known as the clipping point or apex of a corner. Drivers aim for this point as they enter the corner.

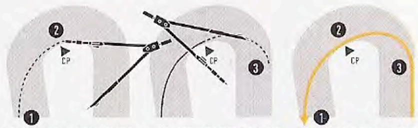
Once the car has gone past this clipping point, the driver can start to straighten the steering wheel and accelerate away - so a corner's clipping point could also be decribed as the the switching point, where deceleration and turning operations change to acceleration. But note that this point isn't actually signposted on the track. As the driver must create an image of the driving line in their head, the clipping point is positioned according to the corner in-the same way.

Column

If you have a diagram of a corner to hand, you can use a pair of compasses to find the best line to take when cornering. Start by setting the clipping point, then trace a large arc to the corner's exit from that point. Add a small arc at the entrance, joining it to the first arc you drew. By drawing these arcs so that they intersect smoothly, you can come up with a workable racing line. Then you need to experiment by actually driving around the corner, and fine-tune to achieve the right line [Fig. 37-1].

Thinking in terms of the basic outside-inside-outside cornering line, the clipping point should be positioned in the middle of the corner. However, in reality, it tends to be better to position it slightly nearer the corner's exit. This is known as a late apex. Setting a late apex makes it possible to accelerate out more quickly, and the total length of the corner over which you are accelerating increases. Since a car's ability to brake is often more effective than its acceleration, maximising the distance over which you can accelerate will improve your lap time. Prioritising acceleration out of a corner is known as the "slow in, fast out" method.

Fig. 37-1



Set the position of 1 at the outside of the corner's exit, and then draw a large arc towards the inside of the corner to 2 [the clipping point].

Next, draw another large arc connecting the clipping point and the outside of the track at the start of the corner. The point where this arc reaches the outside of the track is 3. This is the entry point for the corner.

By reversing this order, 3→2→1, you have the optimum line for taking the corner.

Learn the quirks of your car

Your Car's Behaviour

Understeer and Oversteer

How a vehicle moves when steering is known as its "handling". In this section, we will examine a number of the characteristics associated with handling.

Following a racing line precisely when cornering may serve to maximise your speed, but there's no guarantee that it will go smoothly every time.

There are times when you turn the steering wheel, but the car refuses to turn well, or when it turns more than you intended.

"Understeer" is the term used when a vehicle doesn't turn as much as its driver intends. It is the opposite of "oversteer", which is when the vehicle turns more than the driver intends (Fig. 39-1).

It is often said that cars with FR layouts (front-engine, rear-wheel drive) are prone to oversteering, while cars with FF layouts (front-engine, front-wheel drive) are liable to understeer. However, this is not necessarily the case. There are a whole range of factors that cause both understeering and oversteering. While car layout is an important contributory factor, it is important to remember that FR cars can understeer, just as FF cars can oversteer.

Imagine drawing a large circle in an open space and driving a car around it. If you accelerate while holding the steering wheel in a fixed position and the front wheels slip outward, causing the car to take a wider course than the circle, this is understeering. If the rear wheels slip, causing the car to turn in too sharply and head into the circle, this is oversteering. In both these cases, oversteering and understeering are caused by the driver stepping on the accelerator and transferring power from the engine to the wheels. For this reason, this is known as power understeering and power oversteering.

If a large portion of a car's weight is shifted to the front tyres by braking, the load at the rear tyres will be reduced, and will cause oversteer due to the rear end slipping outward. This is an oversteer condition caused by braking.

There are other types of understeer and oversteer caused by the driver's steering. For instance, turning the steering wheel too sharply or turning it too late can cause understeering. If a corner is entered when going too fast, this can also lead to understeering.

When discussing understeer and oversteer, there is a tendency to confuse cases caused by the driver with cases caused by the car itself, but it is important to learn to distinguish between the two.

The Risk of Spinning Out on a Corner

There is another important characteristic associated with the handling of cars. This is the phenomenon of a car turning in towards the corner rapidly when the driver takes his foot off the accelerator. If the car is at full throttle and the accelerator is let off completely, the vehicle's load is transferred instantly to the front wheels, causing the rear tyres to lose their grip. If this occurs when the steering wheel is turned, the car will veer in that direction and oversteering can result, with the car going into a spin in the worst cases. This occurs most often in FF cars, and one of the best ways to recover if you sense you are going into a spin is to immediately step on the accelerator and increase forward propulsion, thereby causing the car to understeer instead (Fig. 39-2).

Fig. 39-1

Understeer is shown in the diagram at the top, while the middle diagram shows oversteer. The diagram at the bottom shows a neutral driving position.

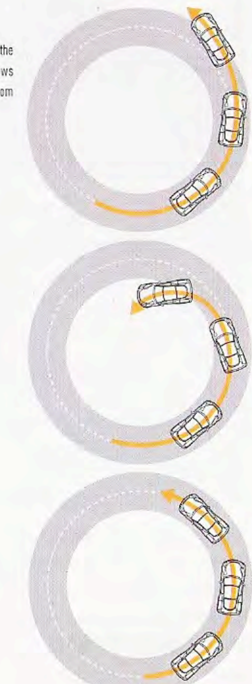
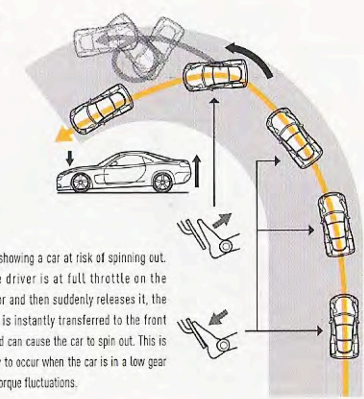


Fig. 39-2



An image showing a car at risk of spinning out. When the driver is at full throttle on the accelerator and then suddenly releases it, the car's load is instantly transferred to the front wheels, and can cause the car to spin out. This is most likely to occur when the car is in a low gear with high torque fluctuations.

Perfecting Your Cornering Skills
CHAPTER 1
Driving Techniques

Perfecting Your Cornering Skills

At this point, you should have a decent grasp of the fundamentals of cornering. However, in the world of driving, things are rarely simple. Let's take a closer look at the finer points of cornering.

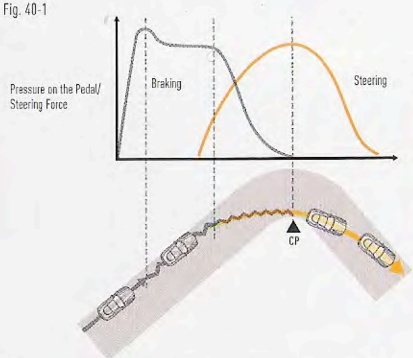
High-speed cornering

Brake Turning

Turn the Steering Wheel While Still Braking

We've looked at the basics of cornering: braking on approach, releasing the brake when you reach the turning speed, then turning the car. However, if you are aiming for faster cornering, it's best not to release the brake too suddenly, but to do so smoothly and gradually as you start to turn the steering wheel. This is known as "brake turning" (Fig. 40-1).

Fig. 40-1



A diagram representing braking and steering when entering a corner. Gradually releasing the brake and turning in towards the corner at the same time, braking is completed when you reach the clipping point of the corner.

If you think about the load on the tyres, it's easy to understand why this is effective. When you brake, all of the tyres' grip is being used to decelerate the car. Even if you try to steer the car at this point, there is no grip to spare, and the car won't turn.

By releasing the brake, you free up grip which can be used to turn the vehicle. But when you are just starting to turn the car, you only need a small amount of grip for turning. This means you can continue to brake as you begin to turn the car, and if you steadily release the brake as you continue turning the car, you'll be able to use the grip of the tyres more efficiently.

The chief advantage of brake turning is that it enables you to delay the point at which you begin to brake - but that's not the only advantage. While braking, the load continues to be placed on the front wheels, which means the grip is very strong when you start to turn the car. This allows you to turn more sharply.

However, there are also drawbacks associated with this technique. If a large portion of the car's load is placed on the front wheels, it means that the load on the rear wheels is that much less. This can lead to decreased stability when steering and may cause the car to slide out, especially in FF cars.

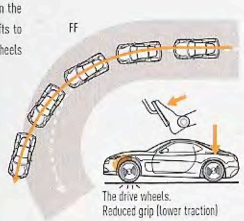
At the same time, a skilled driver can make use of this instability. In cars with a marked tendency to understeer, getting the rear wheels to slide out a little can keep this under control and allow faster cornering.

Changes in Cornering Behaviour Due to Car Layout

When considering how to master high-speed cornering, you should always be conscious of the drive layout (→p.79) of your car.

Both engine power and steering are located at the front of an FF car, which means that about 60% of the vehicle's weight is placed on the front wheels, increasing susceptibility to understeer. Incorrect timing or acceleration as you come out of a corner could cause severe understeer. This tendency may also be seen in four-wheel drive cars with FF or FR layouts (Fig. 41-1).

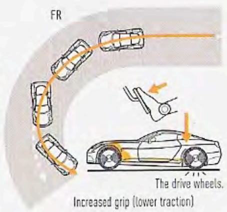
Fig. 41-1
An FF car during acceleration. When the accelerator is pressed, the load shifts to the rear wheels, causing the front wheels (the drive wheels) to lose traction.



In FR vehicles, the front wheels control the steering, while engine power is transferred to the ground through the rear wheels. It is typical for about 55% of the vehicle's load to be placed on the front wheels, though there are FR vehicles which have an even fifty-fifty load distribution between the front and rear. This balance results in improved controllability using the accelerator pedal, which makes these cars more enjoyable in sports driving.

In vehicles with RR or mid-engine layouts, the proportion of the load placed on the front wheels is reduced, which gives the vehicle increased manoeuvrability. At the same time, because a large portion of its weight is at the rear end of the vehicle, centrifugal force acts stronger in the rear end of the car, which can result in slipping and oversteering (Fig. 41-2).

Fig. 41-2
An FR car accelerating. When the accelerator is pressed, the load shifts to the rear wheels (which are also the drive wheels), improving the car's grip. However, if the driver misjudges the timing, the car can be prone to oversteering.



Determining a racing line

A Challenging Corner

Corners With Multiple Clipping Points

Corners come in all shapes and sizes, ranging from simple curves which remain at a constant angle, to long series of twists and turns, to corners where the angle of the curve changes part of the way through. Although following the outside-inside-outside method will work fine for straightforward corners, there are times when things aren't that simple and determining the optimum line for traversing the corner is a little more difficult.

Let's take as an example a corner which starts with a gentle curve before taking a sharper angle. Cars will often dramatically overtake each other on corners like these during races.

It's best to treat a combined bend like this as a single corner (Fig. 43-1). For the optimum racing line, imagine two clipping points, one near the start of the corner and one towards the end. The first clipping point is just a point to set your eyes on, and you should drive in a wide circle around it without approaching it. Once you get past this first clipping point, gradually move inwards and aim to be as close as possible to the inside by the time you are passing the second clipping point.

Next, let's take a look at two consecutive corners requiring you to go left, then right. With this kind of S-shaped bend, if you take the first corner using the outside-inside-outside technique, you'll enter the second corner on the inside of the curve, which will reduce your cornering speed.

The best solution is to try to connect the two corners in the straightest line possible. The best racing line would be to take the first corner by going to the outside, inside, then the middle of the track. On the next bend, you should aim to move from the middle to the inside to the outside, thereby connecting the two corners together smoothly (Fig. 43-2).

Consecutive Corners of Varying Size

The most difficult corners of all are those with two or more consecutive bends of differing sizes. For corners like these, there is no neat rule that fits each and every one. If they contain a short straight section, the speed you achieve on that straight can determine the overall speed through the corner.

The main point to remember is not to get too bogged down in each individual corner. The vital thing is the speed at which you are able to accelerate out of the final turn, as this will determine your speed on the next straight.

In order to open up the throttle quickly as you come out of a corner, you need to start straightening the steering wheel as early as possible. What is the best driving line to take in order to achieve this? Let's calculate it by working backwards from the exit of the corner.

Imagine there being as many clipping points as there are times you need to turn the steering wheel. Just remember that it's not always necessary to go through clipping points when you're in the middle of a series of consecutive corners. There are cases where they simply serve as a guide to keeping you driving on the perfect line.

As corners come in a whole range of shapes and sizes, there is often no substitute for experience. Try driving around the track again and again, noting your speed as you exit the final corner and the total time required to take the entire section. Practice makes perfect (Fig. 43-3).

Fig. 43-1

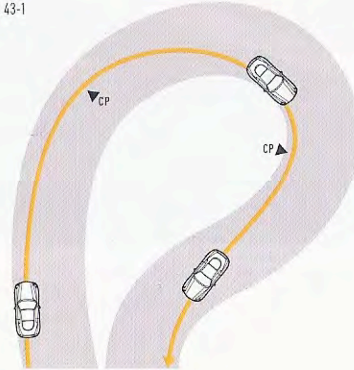


Fig. 43-2

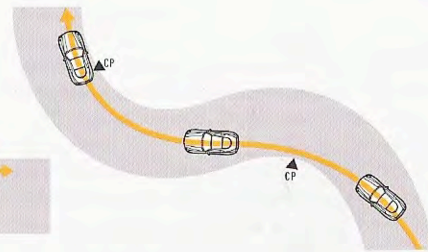
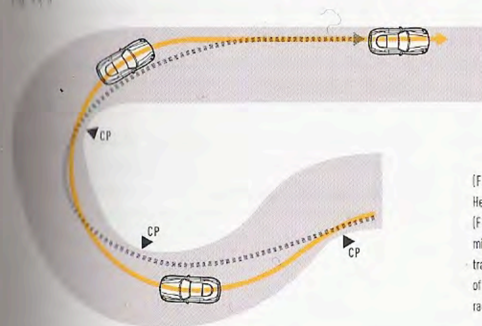


Fig. 43-3



(Fig. 43-1) shows linked corners where the turn becomes sharper partway through. Here, you went approach the inside of the curve aiming to hit the second clipping point. (Fig. 43-2) shows an S-curve. For the first corner, it's best to aim to drive towards the middle of the track upon exiting and then approach the second corner from the centre of the track width. (Fig. 43-3) shows a combined corner. Your aim should be to maximise the length of the final straight. With this in mind, you can work backwards to determine the optimum racing line (shown in yellow).

Extreme slide control

Drifting

Braking and Steering to Maintain Your Position

Deliberately causing the tyres to slide and countersteering in order to take a corner is known as drifting, and is one of the fun parts of race driving. Successful drifting demands a high level of accuracy in braking, acceleration and steering.

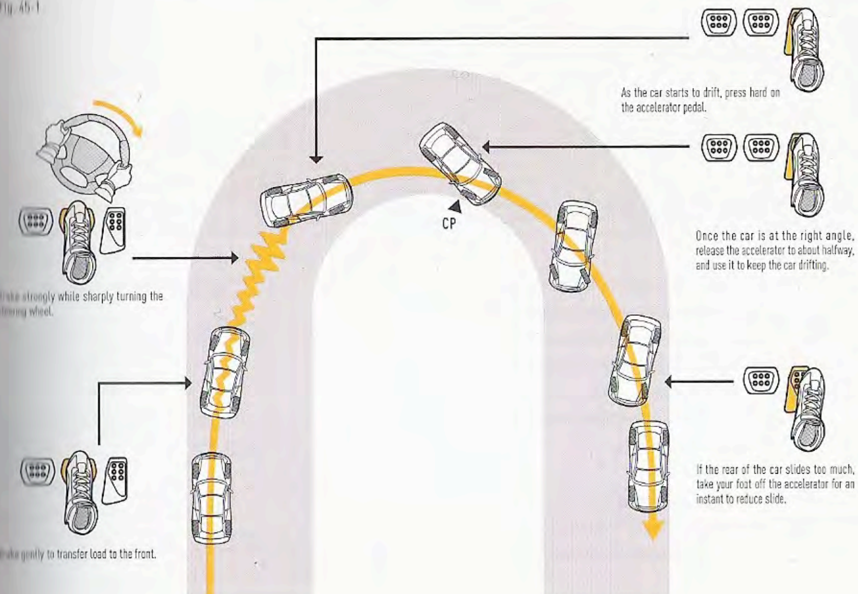
In order to learn how to drift, it's best to divide the process into two. The first part involves entering the corner slightly faster than normal, and applying full brakes. Release the brake slightly and turn the steering, allowing the rear end to slide and setting the angle of your car. Maintain the angle of the car until the exit of the corner by using the accelerator pedal.

Positioning the car correctly at the entry into the corner is a question of getting the timing right for both braking and steering. As an example, apply brakes to transfer the vehicle's load to the front, then turn the steering wheel. Now it will be easier to turn the car because the load on the front is increased, which in turn reduces the load on the rear and makes it easier to slide out. The balance to aim for is where the car begins to turn towards the inside of the corner and the rear end starts to slide lazily.

Modern sports tyres have very strong grip, making it difficult to get the car into a drifting condition. In order to counteract this grip, you need to shift the vehicle's load more suddenly and dramatically. To shift more of the load to the front of the car to make it easier for the rear tyres to slide, it's vital to brake strongly just before you turn the steering wheel. If you still can't get the rear wheels to slide, you can take the rather drastic action of putting on the handbrake at the exact instant you turn the steering wheel.

In drifting, because the rear wheels are sliding, it is important to maintain the grip of the front wheels. Drifting therefore demands particularly smooth steering and careful control of the vehicle (Fig. 45-1).

Fig. 45-1



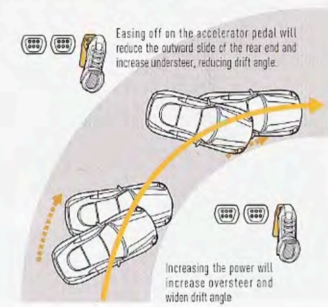
Adjusting Turning Angle Using the Steering Wheel and Accelerator

Once the rear wheels start to slide, the car will start to point towards the inside of the corner. The angle between the direction the car is pointing and the actual direction of travel is known as the drift angle. Once you have achieved the desired drift angle, the next step is to try to maintain this angle until you exit the corner.

If you press the accelerator while drifting, the rear wheels will slide more. If you take your foot off the accelerator, you will stop sliding. You can also stop the car sliding by rapidly turning the steering wheel away from the corner just as you start to slide. This is known as countersteering (→p.49). Since steering operations during drifting also determine the direction that the car travels, the actual steering operation will involve a subtle combination of countersteering and regular steering.

As you start the drifting manoeuvre, slide the car as if you are trying to get it to spin, then countersteer without taking your foot off the accelerator to stop the spin from actually occurring. By repeatedly practising this, you will steadily develop an instinct for how to keep the car drifting (Fig. 45-2).

Fig. 45-2



Advanced technique

Maintain an Image of the Car's Load While You Drive

Always Be Aware of How Load is Moving

To complete our discussion of advanced cornering techniques, let's take a look at the importance of always being aware of the effect of loads on a car. An expert driver will always be aware of how load is being transferred over the wheels as they drive. They will know which wheels need to maintain a strong grip according to the conditions, and will make a conscious effort to transfer load to specific wheels, maximising the grip of the tyres.

For instance, when accelerating, you need to feel the load resting on the drive wheels. It is difficult to transfer the weight to the front wheels during acceleration in an FF car, but it is possible to consciously avoid losing load at the front tyres.

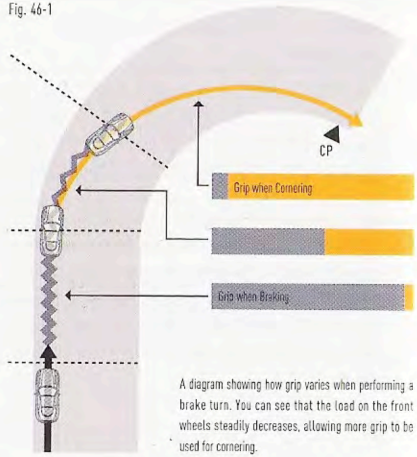
The accelerator and brake pedal are vital tools for transferring the car's load.

It's the same when taking corners that slope upwards or downwards. As mentioned in the opening section about the role of tyres, when the track slopes upwards, the vehicle's load is transferred to its rear tyres, while the load shifts to the front tyres when the vehicle is going downhill.

So if a corner slopes upwards, the resistance of the incline will make braking more effective when entering the turn. However, transferring the load to the front wheels will also become more difficult, making the car prone to understeering. Conversely, when a car goes into a downhill turn, the load placed on the front wheels increases, making steering easier. But if the load on the front wheels becomes too great from the braking, the load on the rear wheels will become insufficient and will result in oversteering.

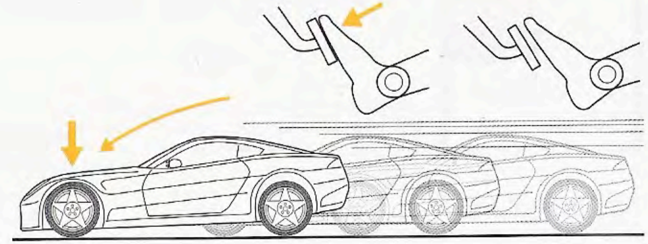
When you encounter this kind of corner, it's vital to take potential oversteer and understeer into account when finding the optimum line (Fig. 46-1) (Fig. 47-1).

Fig. 46-1



A diagram showing how grip varies when performing a brake turn. You can see that the load on the front wheels steadily decreases, allowing more grip to be used for cornering.

Fig. 47-1



When thinking in terms of load, the brakes are used not to slow down, but to transfer weight to the front wheels, thereby increasing their grip.

A Few Important Points About Car Set-Up

A car's load does not just shift from front to back, but also from left to right. When cornering, body roll acts upon the car, meaning that the weight of the vehicle shifts to the wheels on the outside of the turn.

When cornering at high-speed, this transfer of load becomes more pronounced, and the wheels on the inside of the turn can even lift off the surface of the track entirely. In cars not equipped with an LSD (Limited Slip Differential - see page 93), engine power is still transferred to wheels that have come off the road surface, causing them to spin freely, wasting power. Here too, the driver must pay careful attention to the load transfer caused by body roll and utilise this information for setting up the car.

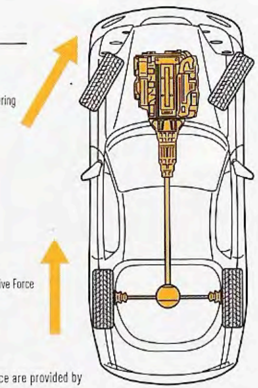
Load transfer can be controlled to some degree by adjusting the car's suspension and height. It can generally be minimised by lowering the vehicle and tightening the suspension. This makes the car's handling more responsive, but if overdone it can prevent the tyres from achieving their full grip potential, which can reduce stability. Always bear in mind that in high-speed motor racing, some degree of load transfer is necessary in order to manoeuvre effectively (Fig. 47-2).

Fig. 47-2

FR

Steering

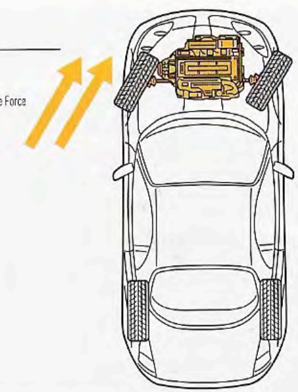
Drive Force



In FR cars, steering and drive force are provided by different sets of wheels. This means that steering ability can be raised by decelerating, and drive force can be gained naturally during acceleration.

FF

Steering + Drive Force



In FF cars, both steering and drive force are provided by the front wheels, which makes it more difficult to divide the usage of tyre grip between the two.

Shaving Seconds Off Your Lap Times
CHAPTER 1
Driving Techniques

Reducing Lap Times

You should by now have a good idea of the basic techniques required for sports driving. Next, let's turn to the required techniques for controlling the car at the very limit of its performance, and also take a closer look at some of the latest innovations in automotive technology.

Heel-and-Toe

Braking and Shifting Down Simultaneously

While clutchless (semi-automatic) manual transmission have become more common in recent sports cars, the mainstream of motor racing is still manual transmission. Heel-and-toe is a technique devised to drive a car with manual transmission faster through corners. The purpose of using heel-and-toe is to shift down simultaneously during the braking process. Braking has a much higher priority here, so if your braking is hampered by adding this technique, you've missed the point.

When shifting down in a manual transmission, you need to step on the accelerator while in neutral to temporarily raise the engine's RPM. This technique involves stepping on the accelerator with your heel while your foot is still on the brake. Take a look at (Fig. 48-1) to see the steps required.

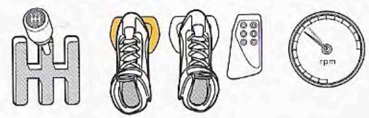
The advantage of this technique is that it allows the driver to accelerate more quickly out of the turn by engaging the gear best suited for acceleration in advance, so that you can start acceleration as soon as possible at the exit of a corner.

Previously, another merit of heel-and-toe was that shifting down a gear allowed the use of engine braking. However, with recent developments in high grip tyres, high performance brakes and ABS (Anti-Lock Braking Systems), the importance of this has waned.

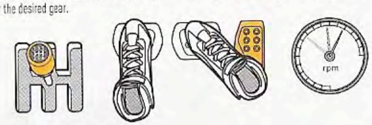
Fig. 48-1

Brake to reduce the engine's RPM to the point where you are able to shift down a gear without over-revving.

Disengage the clutch while still braking.



Enter neutral, take your foot off the clutch, and use the heel of your right foot to press down on the accelerator to increase the revs of the engine so that they are slightly higher than the minimum level needed for the desired gear.



Disengage the clutch again and move the gearstick into gear.

When the revs have dropped to the correct level for the desired gear, engage the clutch and, if necessary, prepare to shift down again.

Preparing to accelerate out of the turn

Countersteering to Prevent Spinning

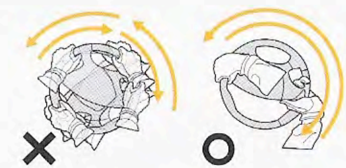
When the centrifugal force acting on your rear wheels becomes too strong during steering, they are liable to slide. The technique of "Drifting" makes deliberate use of this, but the type of drifting that requires dramatic countersteering is by no means a way to shorten your lap times on a paved circuit. Still, when pushing your vehicle to the limit, it is not unusual for the rear wheels to slide, making countersteering necessary in order to prevent the car going into a spin.

Steering in the opposite direction of the turn might seem like a counter-intuitive technique that would require a good deal of practice, but in reality, it is something that most people will do instinctively as a way of getting the car to straighten up after turning. However, inexperienced drivers do have a tendency not to apply the necessary amount of countersteer, either turning the wheel too late or not turning it sharply enough. It's especially important to pay attention to this when driving on race tracks with a high-traction surface or other dry road surfaces.

The most difficult element of countersteering isn't in fact turning the steering wheel the "wrong" way, it's turning it back again. You must judge this from the direction in which the car should be heading and its actual direction, but if you are too slow to turn it back, or turn it too far, the manoeuvre is unlikely to be successful. Gauging the correct amount of turn required is a matter of intuition and repeated practice.

When countersteering, it is vital to perform the action rapidly. Because of this, drivers who tend to change their holding position on the steering wheel when they turn will find countersteering difficult. When countersteering, don't worry about the awkward position of your arms. Don't change your hold on the steering wheel and you will find it much easier to perform the next movement (Fig. 49-1).

Fig. 49-1



After applying countersteer, you will need to return the steering wheel rapidly. This is why it's best not to change your hold on the steering, as keeping your hands in the same place will make it easier to return the steering to a full straight position.

The Benefits of Electronic Driver Assistance

ABS Allows Drivers to Turn as They Brake

With advances in electronic engineering, cars have been able to take control of areas that are beyond the reach of the driver. One example is anti-lock braking (ABS), which has become an indispensable feature of sports cars.

No matter what surface you're driving on, if the wheels lock, braking power is reduced and steering control is impossible. This is where ABS comes in, reducing the braking applied to locked wheels for an instant in order to allow them to recover traction (Fig. 50-1).

ABS reduces the braking force applied to locked wheels, allowing them to recover traction before applying the brake again. It can repeatedly perform this process over the course of a few milliseconds, and can do so to any of the four wheels individually. This is a highly advanced operation that is beyond the control capability of a driver.

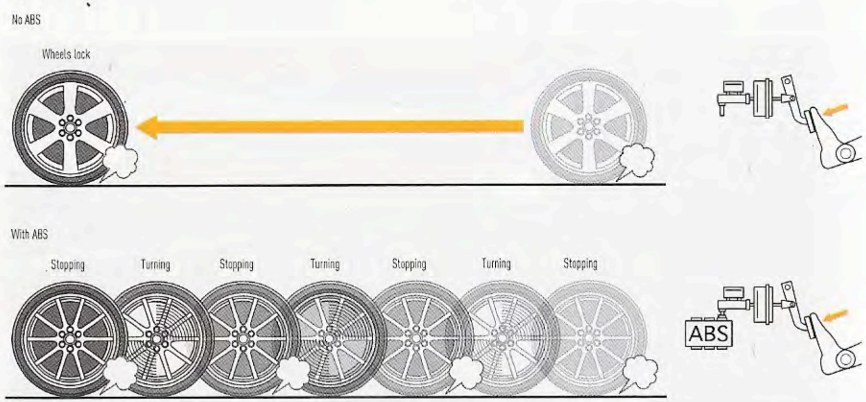
With further advanced ABS, braking can be eased in response to steering. As discussed in the section on the friction circle, when all of the tyres' grip is utilised for braking, none is left for steering, meaning the car will not turn even if the driver turns the steering wheel. The ABS can reduce the braking by minimum levels so as to free enough grip to enable the driver to turn the car.

Along with these developments in ABS technology, stability control systems to prevent the cars from sliding sideways have also been developed, and are now fitted as standard on many sports cars.

These stability control systems are known by a variety of names depending on the manufacturer, including VSC, VDC and ESP, but here we will refer to them using the generic term ESC (Electronic Stability Control). ESC systems automatically apply the brakes of the most appropriate wheels when a car oversteers or understeers, thus keeping it stable. This differs from ABS in that it applies braking even when the brake pedal is not pressed.

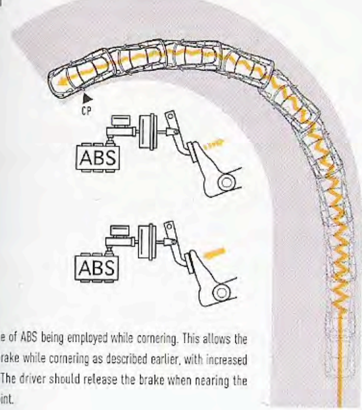
Some cars actively utilise ESC in order to improve handling. A good example of this is so-called "understeering control", which is becoming widely used in high-powered FF sports models. When the car understeers, the system applies the brake just on the rear wheel on the inside of the corner, with varying braking force applied according to the degree of understeer. This allows the wheel to act as a pivot around which the car can turn, thus countering the understeer effect. Developments such as these are proving to be extremely useful in sports driving (Fig. 51-1).

Fig. 50-1



If the wheels become locked in braking, you will not be able to steer (see top). The role of ABS is to detect this and ease the brake hydraulics for a moment, allowing the wheels to recover traction and enable steering again (see bottom).

Fig. 51-1



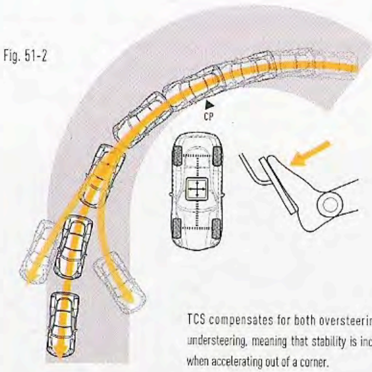
An example of ABS being employed while cornering. This allows the driver to brake while cornering as described earlier, with increased stability. The driver should release the brake when nearing the clipping point.

TCS Enables Controlled Turning as the Car Accelerates

A Traction Control System (TCS) prevents wheelspin caused by over-acceleration as a car exits a corner. When its sensors determine that the wheels are slipping, the TCS makes subtle adjustments to the engine power. As the TCS automatically adjusts engine power to keep the car just below the point where the tyres will start to slip, all the driver has to do is step on the accelerator. This system really comes into its own when rain or other factors have led to poor surface conditions.

However, there are cars whose TCS settings are such that they put too much emphasis on preventing slip, meaning that the car cannot achieve its full potential acceleration. It is well worth remembering that, with the exception of high-powered FF and FR cars, or under wet weather conditions, it's usually better for the driver to take care of skid control themselves (Fig. 51-2).

Fig. 51-2



TCS compensates for both oversteering and understeering, meaning that stability is increased when accelerating out of a corner.

The benefits of electronic devices

Techniques for Winning

CHAPTER 1
Driving Techniques

Techniques for Winning

The aim in any race is to be the fastest driver past the finish line, but achieving victory is not just about speed – you need a variety of strengths. Let's look at some advanced techniques to ensure that you overtake your rivals without letting them get past you.

Getting Ahead of Your Rivals

Getting Off to a Good Start

To place at the top of the table, your performance on the opening lap is of crucial importance. The state of general confusion and disorder in the initial stages means there are lots of gaps you can sneak into. In particular, when a race begins from a standing start (where the cars are all stationary), the whole course of the race can be determined by decisions made in the first few moments.

When the light turns green and the cars pull away, drivers will jostle furiously for position on the approach to the first turn. It is generally advantageous to head for the inside of the corner, but since so many cars flock to this position, there are times when, if there is space left on the outside, a well executed outside-outside line on the first corner can put you ahead of the pack. Remembering that it is not always best to stick to the inside of a corner can give you an early advantage.

The important thing is to be able to adapt to any condition, and you should have a few possible routes mapped out in your head before the race starts. It's important to look well ahead, weigh the current situation and aim for the position that will give you the advantage.

Rolling starts, where the cars are already in motion when the race begins, are often used in endurance races. Here, it's important to keep your eye on the movement of the cars in front, so that you can match the start timing. If you can match the acceleration of the lead car, it's likely that you will be able to pass other cars and improve your position as soon as the race begins.

Aiming to be first into the corner

Exploit Your Rivals' Weak Points

Vying with other drivers for supremacy is what makes racing exciting. You might not achieve your best lap time, but if you reach the chequered flag first, you've won and that's all that matters. It is not just about speed, it's the competition between the drivers that makes a good race.

Of course, if your speed is greater than that of the other drivers, all you have to do is overtake them. The problem arises when your laptimes are close, and you cannot pass them or leave them behind. In this situation, you must try to determine the differences between your speed and that of your rivals. Is your car faster on the straight? On low speed corners? On high speed corners? It is crucial to identify factors like these - and in that respect, it can even be an advantage to be a chasing car rather than the leader, as this gives you the chance to assess your opponents.

One good strategy is to surge towards the inside of the corner when braking and gauge your rival's reaction. You can also attempt to vary your line as you exit a corner. If your opponent overreacts and tries desperately to block you, you may well have hit upon a weak point you can exploit.

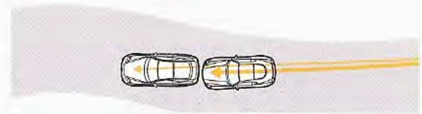
If you judge that you have superior acceleration and speed on the straight, make the most of it by putting your foot down on the straight, lining up with your opponent, then passing them during the braking for the first corner.

Column

In a tail-to-nose confrontation, you need to be careful to avoid engine trouble. If you are in the car behind, there is almost no gap between the front of your car and the rear of the car ahead. Depending on the type of car, this can mean that your radiator receives no ventilation at all, leading to overheating. If you're driving a turbo model with intercoolers mounted in the front, you need to be particularly aware of this.

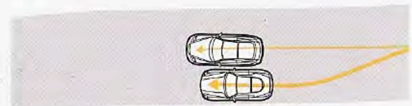
When you're right behind a rival and want to overtake them, it's often not enough simply to sit passively and wait for an opening. You need to shake up your opponent by driving tail-to-nose (Fig. 53-1) or side-by-side (Fig. 53-2) as this can create the opportunity to get ahead.

Fig. 53-1



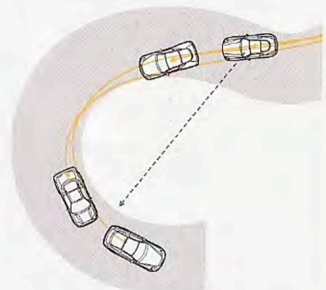
Tail-to-nose driving, where you follow closely behind your rival.

Fig. 53-2



Side-by-side driving, where the aim is to hassle and unnerve your rival.

Fig. 53-3



Most races will have a lot of vehicles taking part, so you need to be aware not just of the action immediately ahead of you, but of how events are unfolding in the race as a whole.

Aim for the inside or attack from the outside?

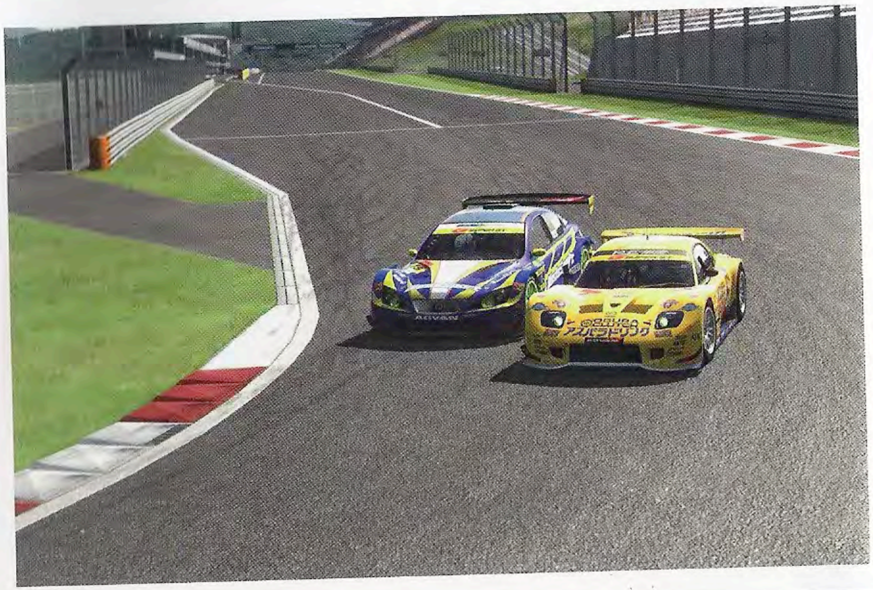
Overtaking on Corners

The Braking Contests that Decide Victory or Defeat

A race track consists of a series of interlinked straights and turns. The area where overtaking most typically takes place is the braking zone in the lead-up to a turn, and whether you overtake your rivals or are passed by the vehicles behind is dictated almost entirely by your braking performance here. This is particularly the case on corners that demand sharp braking from high speeds, which means that tight corners immediately after straights are often prime overtaking spots.

Imagine that you are accelerating on a straight, in hot pursuit of a rival. If you manage to line up side-by-side with your opponent, you're halfway to success. Now, with the next turn in sight, a braking contest begins between you and your opponent whereby the first to brake will lose. If you wait too long to brake, however, the car will not decelerate enough and, in the worst case scenario, will drive off the track.

If you win the braking contest, you'll be able to take the best line going into the corner, allowing you to overtake your rival (Fig. 55-1).



Sacrificing Precious Seconds to Emerge Ahead of Your Rivals

It's absolutely vital to remember that there is a fundamental difference between the type of braking required when you are aiming for the fastest lap time in qualifying and the type of braking used to overtake a rival.

In both cases, rapid deceleration is required, but while in qualifying your overriding priority is to gain the maximum exit speed as you come out of a bend, in competitive driving your goal is to overtake your rival, even if it means sacrificing speed to some degree. For instance, going into a corner too aggressively can lead to a loss of valuable time, and in qualifying it pays to avoid this. When racing, however, the aim is to get ahead of your rivals at all costs. Therefore, even if you lose some acceleration coming out of a turn, as long as you've overtaken the other driver, you've been successful. When trying to out-brake a rival on the approach to a corner, aim to hold off braking until a little after the usual limit for gaining the best time. (Fig. 55-2).

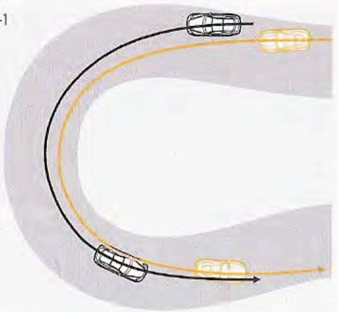
You can also use the approach to a corner to force your opponent to deviate from the racing line, and overtake them as you accelerate away (Fig. 55-3). You can also bluff your opponent by making it look as though you are going towards the inside of the corner on the approach. If they take the bait, they will drive the inner side of the track in order to block you, which means that their acceleration out of the corner will be slower. You can then immediately take the corner using the outside-inside-outside technique. Since your cornering speed will be higher and you will be able to accelerate earlier than your opponent, this could very well place you side by side by the next corner.

When racing, it's no exaggeration to say that nothing is more important than getting ahead of your rivals, even if it means sacrificing your laptime.

Column

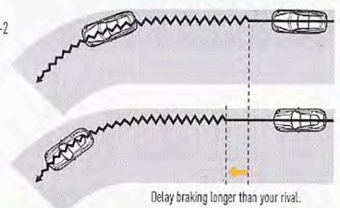
In a race, it's also essential that the drivers trust each other's abilities and uphold some basic manners. For example, if a rival is already on your inside as you enter a corner, it's important to drive in a line that leaves space for their car to take the inside line, and not block them in a dangerous manner to force them out. This trust also applies in the other direction: if you're on the inside of a rival and you're racing side-by-side as you exit the turn, it's an important part of racing etiquette not to swerve too far to the outside, and to leave sufficient space for your rival's car.

Fig. 55-1



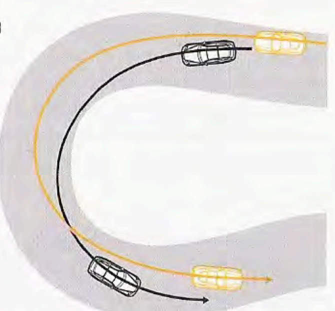
The orange car is yours, while your rival is in the black car. If you are fast enough on the straight leading up to the turn, you can get on the inside of your rival and take the optimum racing line.

Fig. 55-2



If you're jostling for position as you enter the curve, try to hold off on braking in order to get ahead of your rival, even if it means straying from the ideal racing line.

Fig. 55-3



If you end up further into a corner because of delayed braking, adopt a line which focuses on exit speed and accelerate out of the corner as fast as you can.

Using slipstream

Overtaking on the Straight

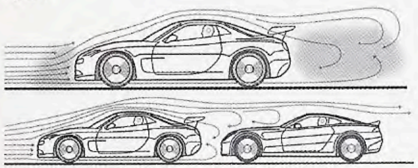
Pluses and Minuses of Using Slipstream

An area of low-pressure air builds up in the wake of any fast-moving vehicle. The low air pressure creates a flow of air that draws air inward, and this phenomenon is known as the slipstream. Air resistance is reduced in this area, making it easier to follow the car creating the slipstream. This can be used to your advantage when overtaking on the straight (Fig. 56-1).

The slipstream effect becomes more marked as the speed, size and height of the vehicle in front increase. The merits of utilising this effect for overtaking is that there is little risk of contact with the car in front, and it places less strain on your car and engine. At the same time, you must exercise caution when exiting a slipstream in order to overtake. When leaving an area of low pressure and suddenly thrust into an area of high pressure, your car is liable to become unstable. There can also be pockets of turbulence around the slipstream which can destabilise your car and, in extreme cases, cause you to lose control of your vehicle (Fig. 57-1).

It's also vital to choose the right moment to overtake using slipstream. If you make your move too early, the rival you've overtaken could turn the tables, enter your slipstream, and be back in front of you by the end of the straight. On the other hand, although the ideal point to overtake is often the straight leading up to a bend, this is also the point when you will be slamming on the brakes from high speed, and your car will be unstable as is, even without the added effect of moving out of a slipstream. Therefore, a precise control of your vehicle is required to succeed.

Fig. 56-1



An area of low pressure builds up behind a car driving at speed. By making use of it, you can extend your top speed while using less power.

Tyre Management

Close-Range Rivalry Causes Rapid Tyre Deterioration

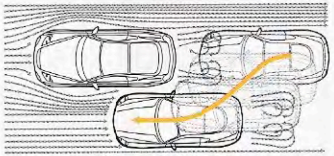
When you're trying to pass a rival, both your car and the car in front will be manoeuvring more and will stray from the racing line more often. Due to the fact that this is the line that most cars will be following, the racing line on a track will absorb rubber from the tyres, serving to improve traction. However, away from the racing line, this layer of rubber is not present, making it comparatively easier to slip.

More serious than this is the issue of tyre deterioration due to excessive stress. When tyres wear down over the course of a race, the layer of rubber on the tyre with the highest traction becomes worn down. Although racing tyres are designed to have very strong grip, the downside is that they wear down extremely rapidly. Excessive braking and irregular steering lead to high levels of abrasion on the surface, meaning that tyres are worn down sooner (Fig. 57-2).

It's also extremely important to bear in mind tyre wear caused by heat. Racing tyres generate heat due to friction with the track surface, causing the surface rubber to melt, and the adhesive property of the tyres in this condition holds the tyres to the track. However, maintaining the tyres at the appropriate temperature for this is extremely important. If excessive friction causes overheating, too much rubber will melt and become soft, leading to a large reduction in grip. This will make the car more prone to both oversteering and understeering, and will have a negative impact on handling (Fig. 57-3).

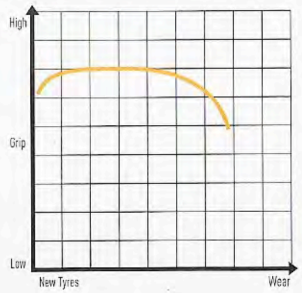
When engaged in tight manoeuvring to gain position, some deviation from the optimum racing line is inevitable, but if you are in close pursuit of a rival, it's worth keeping a cool head, allowing a little space to open up between you and the vehicle in front and taking a line that will minimise strain on your tyres.

Fig. 57-1



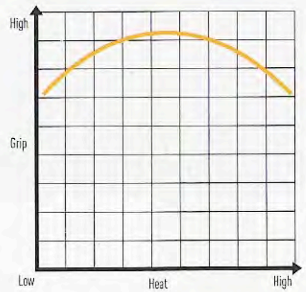
Be aware that there can be severe turbulence when you move out from behind a car you've been pursuing closely.

Fig. 57-2



Tyres only maintain their condition for a certain period before grip begins to deteriorate.

Fig. 57-3



For tyres to gain traction, they need to generate a certain level of heat. The level of heat generated by tyres is affected by the temperature of the track and the friction of the tyres. When tyres heat up, their air pressure increases, so it's also important to anticipate this when adjusting tyre pressure.

Overcoming Difficult Conditions
CHAPTER 1
Driving Techniques

Overcoming Difficult Conditions

If you can achieve high speeds on challenging surfaces like wet, slippery tracks, or unsurfaced dirt roads, then you qualify as an expert driver. Let's take a look at how to overcome difficult driving conditions – a true test of your skills behind the wheel.

Car Control on Wet Surfaces

Taking Surface Traction (μ) Into Account

Driving in wet conditions can be extremely challenging. Rather than simply being a matter of reduced surface traction, the issue is more that traction is no longer uniform. In wet conditions, factors such as the location, temperature and level of rainfall all contribute to making the road surface dauntingly irregular.

Additionally, when driving in wet conditions on faster parts of the track, your tyres cannot rid themselves of water fast enough, meaning that you can end up driving on a film of water in a phenomenon known as hydroplaning or aquaplaning (Fig. 59-1). This can not only cause you to lose speed, but can also cause to the car slide off the track altogether.

This deterioration in the car's performance can however be compensated for by employing driving techniques that make use of the increased slipperiness of the track's surface. There have actually been some top drivers who regarded wet weather as a bonus. Ayrton Senna is one example. Senna debuted as a pro driver in 1984, and at the F1 Monaco GP - held in torrential rain - he managed to come in second behind Alain Prost, whom he had put under enormous pressure despite his car being far from the the fastest car on the track. Senna went on to win a large number of races in wet conditions and eventually became a three-time world champion.

Driving, turning and stopping with more finesse

In more recent years, in the 2008 Italian Grand Prix, both the qualifying and the race itself were held in rainy conditions. Sebastian Vettel, who was already seen as one of the favourites to take the championship, started from pole position and won his first Grand Prix in conditions that were far from ideal.

When driving in wet conditions, you should do your best to avoid sudden, dramatic movements. Accelerating, braking and steering should all be performed in a calm, measured manner. You should also be prepared to deal with oversteer and understeer, and always be ready to respond swiftly to sudden sliding movements of the car.

Wet-Weather Braking Points and Racing Lines Differ from Those in Dry Conditions

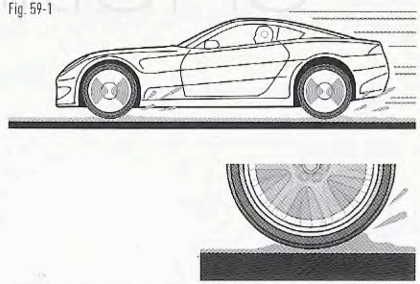
When driving in wet conditions, you need to rely on the feedback from the steering to judge the state of the tyres and road surface, to find the very limit of where the tyres will not slip. A correct driving position is vital, as you need to focus on subtle signals communicated via the steering wheel and through the bottom of the seat.

Cornering becomes incredibly challenging in wet conditions, and in order to prevent understeer and oversteer, it's important to begin braking earlier than you would if you were going into a corner in dry conditions, and to exercise more precise control over your braking (Fig. 59-2).

There are also cases where the racing line differs dramatically between wet and dry tracks. When the surface is dry, you should generally take the optimum racing line. When it is wet, however, puddles of water can build up on the inside of the corners. This means that there will be cases where you have to adopt an outside-outside-outside course in order to avoid the water. You need to be constantly aware of the amount of water on the track as you drive. Also, bear in mind that the rubber coating that can build up along the racing line (→p.56), can actually make the track more slippery when wet, rather than increasing traction as it does in dry conditions.

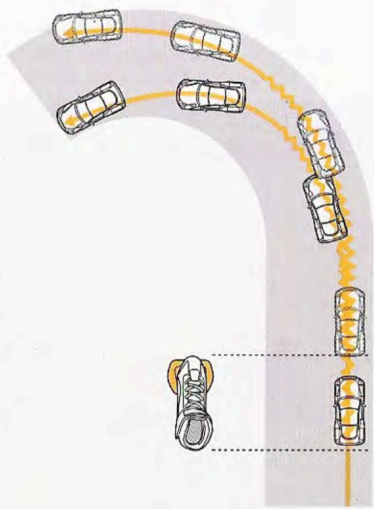
In this section, the importance of careful driving has been emphasised, but if you focus entirely on driving in a controlled manner, you won't be able to achieve high speeds or stand a chance of winning. In a race in difficult conditions, don't rush to get into first place. Instead, hang back a little and pick up useful information by observing the cars in front. This will help you come up with the best strategy for the conditions.

Fig. 59-1



In wet conditions, tyres often struggle to rid themselves of surface water when driving at speed, meaning that the car ends up driving on a film of water. This is known as hydroplaning or aquaplaning.

Fig. 59-2



One of the most basic skills when driving in wet conditions is to allow more time for braking. Puddles can build up on the inside of turns, meaning that you'll need to adapt your line to avoid them.

Strategies for Driving on Gravel

Special Tyres for Different Road Surfaces

Gravel roads are roads that haven't been surfaced, unlike tarmac roads with asphalt or concrete. Gravel consists of everything from hard soil, sand and mud to pebbles. This means that the level of traction the wheels gain on the surface can vary enormously, and drivers need to constantly adapt their strategies in response to these changes.

For instance, on a very hard dirt track, wheels can gain sufficient traction to leave black tyre marks on the surface. Conversely, on surfaces covered in loose, round pebbles (known in Australia as "ball bearing roads"), the traction can be as low as it is on snow. Moreover, when it rains, different parts of the surface will become more slippery than others, and inexperienced drivers may find it difficult even to stay on the course.

Due to the size of their tread blocks and their flexible structure, gravel tyres (Fig. 61-1) optimised for these kinds of surfaces have inferior grip and are less responsive to the driver's controls compared to sports or racing tyres on paved roads. However on gravel they maintain traction and give a high degree of control.

Typical tyres give traction by gripping the road surface. Gravel tyres do more than just grip – they are designed to achieve extra traction by clawing into the road surface. By doing so, they suppress the loss of grip even if the slip ratio or slip angle becomes large.

A changing road surface calls for a high level of stability and control, so that even if the grip level of the road surface is reduced, control of the car is not drastically reduced. A large range of gravel tyres is available, each suited to a particular type of surface. It goes without saying that selecting the tyres best suited to the road surface is a basic requirement for being able to drive safely at high speeds on gravel.

Flexible Judgement and Control in Every Situation

Even on a gravel surface, the basic outside-inside-outside line for cornering holds true. However, since the surface is not uniform, the driver needs to gauge the nature of the surface ahead and select a line that keeps the car on the parts of the track with the highest traction. There are also times when the driver will need to take an outside-outside-outside line in order to avoid rougher sections on the inside of turns. Cars' tyres dig tracks in softer dirt surfaces, and the tracks created by the car in front can sometimes be followed like the rails of a rollercoaster.

Learning to read wildly varying surface conditions

When courses are set on natural terrain, it can lead to bumps, swelling and unevenness that can cause a car to jump when it hits them at high speeds. This is something you will often see in footage of rally racing.

If you hit these jumps without slowing down, the car will take to the air in a fast, high jump with the front floating upwards (Fig. 61-2). If you take your foot off the accelerator just before hitting a jump, the car will jump with its front pointed downwards (Fig. 61-3). The best way to take a jump is said to be to hit it at full throttle but to apply a little brake with the left foot. This will make the car fly a considerable distance while remaining low. When a jump is positioned just before a turn, you need to turn the steering wheel before you hit the ground. Be aware that with relatively low speed jumps, the front to rear weight distribution of the car can also affect the angle of the car in a jump.

Fig. 61-1

If used on surfaced roads, gravel tyres have inferior grip and responsiveness compared to regular tyres. They come into their own on unsurfaced roads, where they provide high levels of grip and control.

Column

A strong structure is crucial for gravel tyres, which are designed to be used on extremely rough surfaces covered with rocks, potholes, bumps and other obstacles. A high level of traction is required, but an ability to withstand shock and impact is just as important. Slick tyres with no tread, similar to those used on paved racing circuits, are occasionally used on gravel, but their internal structure is completely different despite their appearance.

Fig. 61-2

If you hit a jump at full throttle, the car will take to the air with its rear end hanging downwards.

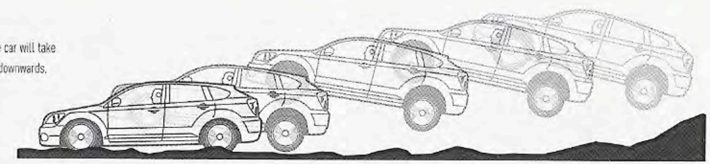
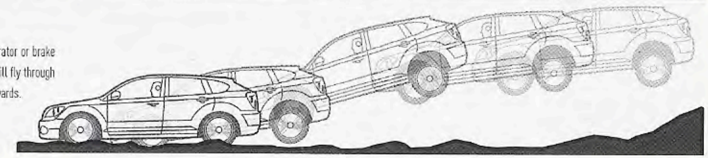


Fig. 61-3

If you take your foot off the accelerator or brake just before hitting a jump, the car will fly through the air with its front hanging downwards.



Overcoming limited traction

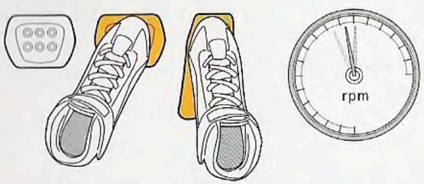
Tactics for Handling Gravel Surfaces

Left-Foot Braking

Left-foot braking is a technique well worth learning if you are going to be racing on gravel. When braking simply to slow the car, it doesn't matter whether you brake with your right or left foot, but if you need to adjust the car's position when cornering, or want to keep your revs steady, you need to use your right foot for the accelerator and the left foot for the brake. In rally events, it's not unusual to see the brake light remain on until the driver has seen the exit of the corner.

There are also special braking techniques for use on gravel surfaces. On a regular race track, braking is performed in a straight line before the beginning of a corner to stabilise the car. On gravel, however, deceleration is often combined with an action which swings the car sideways. This style of braking is peculiar to gravel surfaces, and allows you to decelerate quickly by using the increased resistance of the car turned sideways alongside the effect of braking on the uneven surface. [Fig. 62-1].

Fig. 62-1



Make frequent use of left-foot braking on gravel to give yourself more control over the car's orientation.

Deliberate Sliding for Faster Turning

As wheels lack traction on gravel surfaces, naturally they are more prone to sliding. Because of this, drifting will not adversely affect your time around a course. In fact, rally cars are tuned to make them easier to drift, with high levels of torque. Their tyres are also designed so that even if they are in a slide, they will not lose too much traction. Drifting is actually an indispensable technique for driving fast and safely on a gravel course.

Upon entering a corner, the car is turned sharply inward well in advance, and thereafter the focus is just on controlling speed. Fast rally drivers may appear to be launching themselves into a large slide as they enter corners, but as they exit, their cars will be orientated in a straight position towards the exit of the corner, most advantageous for rapid acceleration. It is because this actually minimises the loss of time.

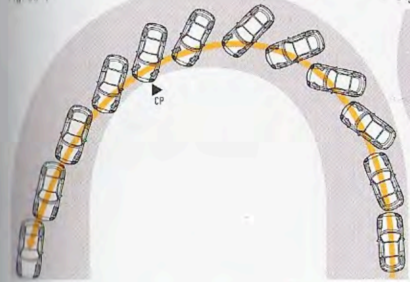
Even from a safety perspective, drifting has its advantages. Should you misjudge the size of a corner and enter it too fast when drifting you can slow down naturally by easing off the accelerator and allowing the resistance of the tyres to slow the car down. If you determine that you can clear the corner, you can step on the accelerator and sharpen the angle of the drift to exit the corner. This high level of control is an advantage of drifting and allows you to drive with an increased safety margin.

In order to drift on a gravel surface, you first need to enter the corner at a faster speed than you would to turn without drifting. Then, shift the car's load to the front wheels by easing off the accelerator or using the brake, and sharply turn the steering wheel.

By doing this, you can enter the corner in a drifting condition. If it's difficult to start drifting, you may need to use the handbrake as well. Also, depending on the circumstances, you can adjust the drift angle using countersteering and accelerator control, combined with left-foot braking. In order to achieve the maximum speed as you exit the corner, you should straighten the steering wheel just before the car points towards the exit of the turn. [Fig. 63-1].

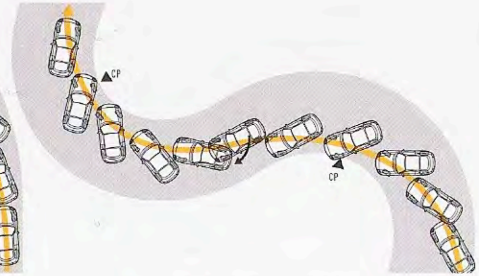
You can also apply these skills when traversing S-shaped bends. When a turn twists right then left, you can take the first turn by drifting, and without having to straighten the car, you can use your momentum to launch yourself into a drift around the second turn. [Fig. 63-2].

Fig. 63-1

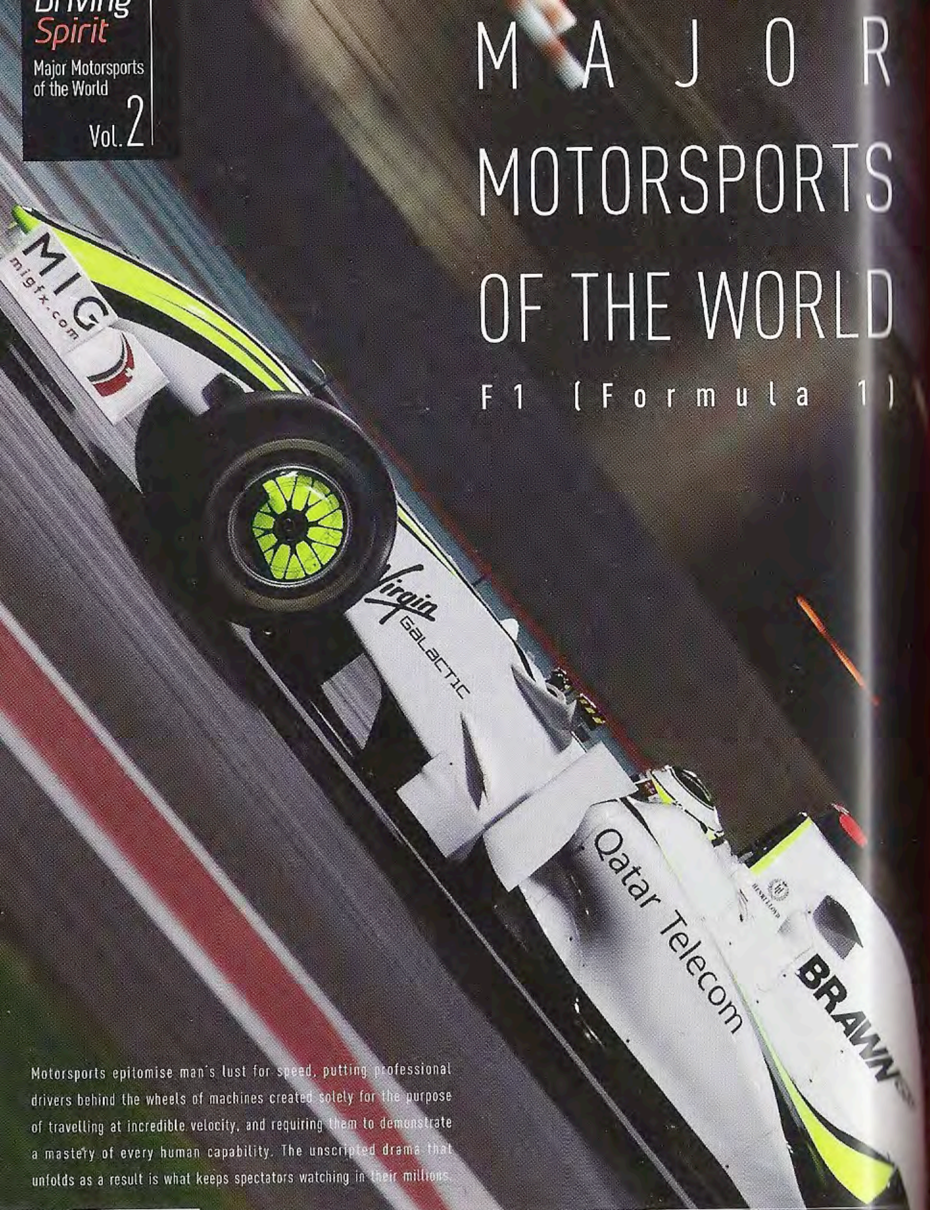


The ideal way to drift on gravel. The objective is to point the car towards the exit early, in order to gain more time for acceleration.

Fig. 63-2



Drifting to clear an S-shaped corner. You can use the momentum from drifting around the first corner to drift into the second corner.



Driving Spirit

Major Motorsports of the World

Vol. 2

MAJOR MOTORSPORTS OF THE WORLD

F1 (Formula 1)

Motorsports epitomise man's lust for speed, putting professional drivers behind the wheels of machines created solely for the purpose of travelling at incredible velocity, and requiring them to demonstrate a mastery of every human capability. The unscripted drama that unfolds as a result is what keeps spectators watching in their millions.

WORLD MAJOR MOTOR SPORT
FIA Formula One World Championship

CATEGORY Formula

F1 (Formula 1)

Formula 1 is the most elite of motor sports, and the F1 champion is undisputedly the world's fastest driver and machine.

The first ever F1 was held in 1950 at England's Silverstone circuit, and the sport has gone on to become the absolute pinnacle of motorsport. The F1 season is widely recognised as one of the world's top three sporting events, alongside the Olympic Games and the FIFA World Cup, and it's easy to see why when you look at the cars with their slick tyres and hugely powerful engines that push the boundaries of technology, achieving top speeds that easily exceed 300 kilometres per hour (186 mph). The F1 season is centred in Europe, but races are held all over the world. The overall winner is decided by the total number of championship points, awarded based on the finishing position in each race. With the continual advancements in automotive technology in recent years, the F1 now has many interesting highlights other than just the racing.

WORLD MAJOR MOTOR SPORT
GP2 SERIES

CATEGORY Formula

GP2

Up-and-coming youths battle it out to become the next generation of F1 drivers.

This European formula car championship series was introduced in 2005 to replace the International Formula 3000 Championship. Held as a support race for the F1 European round, and using cars closely resembling those of F1, GP2 attracts a great deal of attention because it is seen as the gateway to F1 success, and quite rightly so - many drivers crowned as champions in this series have gone on to achieve great success in F1.

WORLD MAJOR MOTOR SPORT
Japanese Championship Formula Nippon

CATEGORY Formula

Formula Nippon

This is the top of open-wheeled motor racing in Japan, where the skills of the country's top drivers are pitted against one another.

Formula Nippon represents the apex of open-wheel motorsports in Japan. Launched in 1996 on the back of the F3000 wave that swept the world at that time, the season consists of a series of races held at circuits all over Japan. Top Japanese drivers and even some renowned drivers from overseas compete under equal conditions, exploiting every ounce of technique at their disposal in this competition for speed.

WORLD MAJOR MOTOR SPORT
Indy Car Series

CATEGORY
Formula

I R L

The Major League of motorsports.

The IRL is a formula race which, along with F1, stands at the summit of global motorsports. Properly known as the Indy Racing League, it is made up of the IndyCar Series and the Indy Lights Series. In America especially, it enjoys a level of popularity surpassing that of F1. Every year over 400,000 fans flock to the series climax, the Indianapolis 500, an event that has come to symbolise American motorsports. Many races take place on oval courses where both speed and strategy are essential in order to emerge victorious. The side-by-side, tail-to-nose, close quarters combat, which takes place at an average speed of 300 kilometres per hour (186 mph), leaves spectators breathless.

WORLD MAJOR MOTOR SPORT
FIA World Touring Car Championship

CATEGORY
Touring Car

W T C C

Touring cars battle it out to determine the world champion of touring cars.

The World Touring Car Championship was established in 2005, drawing on the momentum of the European Touring Car Championship (ETCC), and represents the zenith of touring car racing. Sanctioned by the FIA, it is the organisation's third-largest championship after the F1 and the WRC. Racing takes place using production cars modified according to specific regulations, including stringent vehicle specifications and weight handicaps, all of which leads to some truly nail-biting action. Host countries and circuits differ from season to season. Though based mainly in Europe, of the 2009 season's 12 events (24 races in total), several took place in South America and Asia.

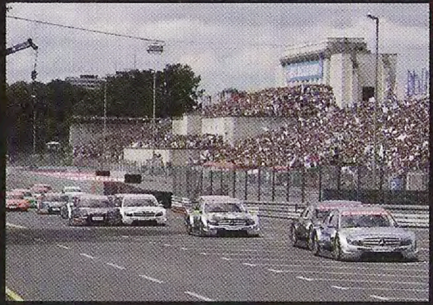
WORLD MAJOR MOTOR SPORT
Deutsche Tourenwagen Masters

CATEGORY
Touring Car

D T M

Germany's own category of racing, popular amongst former F1 drivers.

The DTM is a competitive racing series, hugely popular in Germany, in which highly-tuned touring cars fight for supremacy. Former F1 drivers, including Jean Alesi (2002-06), Mika Häkkinen (2005-07) and Ralf Schumacher (2008-) have taken part, testifying to the world-class standard of the competition.



WORLD MAJOR MOTOR SPORT
FIA GT Championship

CATEGORY
Touring Car

F I A G T

A battle of supercars that bristles with high-octane excitement.

The FIA GT ranks as the top racing category for GT vehicles. This intense battle of the supercars, including the Maserati MC12, Aston Martin DBR9, Lamborghini Murciélago R-GT and Ford GT, continues to reward spectators with incredible levels of excitement. It has been confirmed that the Nissan GT-R, the pride of Japan's supercar scene, will also be entering the fray as of the 2010 season, and expectations of its performance are high.

WORLD MAJOR MOTOR SPORT
SUPER GT

CATEGORY
Touring Car

S U P E R G T

Where racing machines based on Japanese sports cars clash.

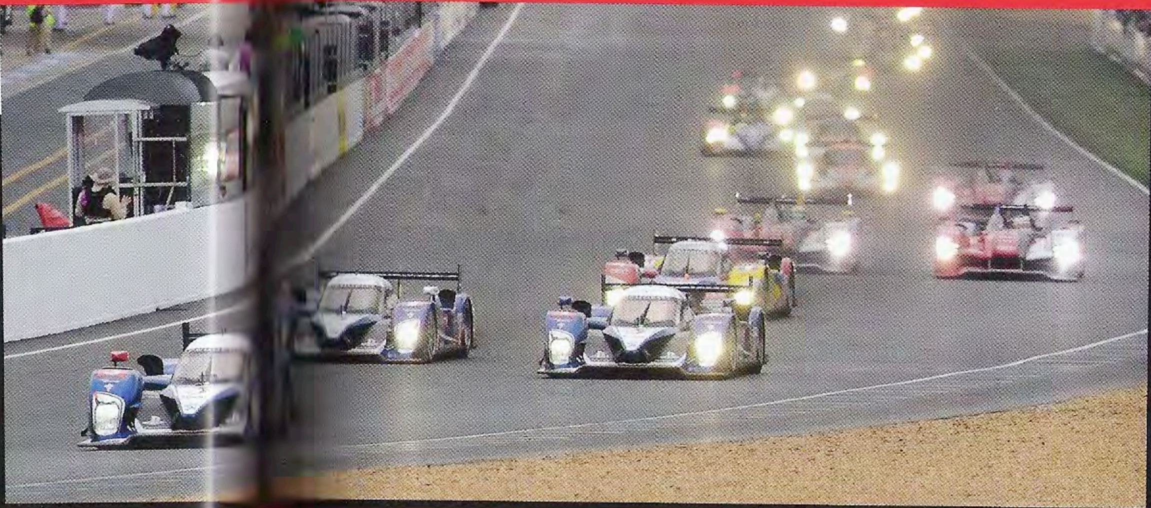
In Japan, Super GT has gained the most popularity of any racing category. GT500 and GT300 class vehicles race together, and victory is determined not just by the potential of the vehicle but also by team strategy, which must successfully combine driver technique and weight handicap considerations. Production cars form the basis for the vehicles competing in this category, but teams are given a large amount of freedom to make modifications, affording them the chance to transform their cars into thoroughbred racing machines.

CATEGORY
Prototype racing car, Touring Car

Le Mans 24 Hours

The ultimate automobile endurance race.

This race, held every year in the suburbs of Le Mans, France, belongs to the "Triple Crown of Motorsports", alongside F1's Monaco Grand Prix and America's Indianapolis 500, and is also the world's most well-known endurance race. Steeped in history, it was first held in 1923 and, despite a few cancellations, the race has been held 77 times as of 2009. Participating teams are mostly European but, in the past, Japanese manufacturers including Toyota, Nissan, Mazda and Honda have taken part with works (or semi-works) cars. Most notably, a Mazda 787B achieved an overall victory in 1991, and its victory is still the stuff of legend in Japanese racing circles to this day.



CATEGORY
Touring Car

Nürburgring 24 Hours

The world's largest-scale touring car endurance race.

The 24 hour race at Nürburgring – best known as a test circuit for a variety of major automotive manufacturers – is the largest-scale touring car endurance race in the world. Seen by some as the toughest race of them all, it takes place on a 26-kilometre (16-mile) course, which connects the old North Course - a winding track with as many as 170 turns including blind corners and an astonishing 300-metre height difference - and the modern GP course, where F1 is held. In recent years, an increase in the number of participating teams has fuelled an incredibly intense level of competition.

Photo by: Gruppe C Motorsport Verlag GmbH, Duisburg

CATEGORY
Prototype racing car, Touring Car

Daytona 24 Hours

A 24-hour battle at the spiritual home of NASCAR.

The Daytona 24 Hours race is the only 24-hour endurance race in America, and takes place on the Daytona International Speedway in Florida, a Mecca for fans of NASCAR. As in the Le Mans, three drivers pilot one vehicle, and the team that travels the farthest within a 24-hour period is declared the winner. It began in 1962 as a 3-hour race, and took on its present 24-hour format in 1966. Amongst the Japanese vehicles that have participated over the years, the Nismo R91CP that took part in 1992 achieved a historic first place finish, claiming overall victory with the combination of a Japanese car and Japanese drivers (Hasemi Masahiro, Hoshino Kazuyoshi, and Suzuki Toshio). Their record total-distance-travelled of 4365.7 kilometres has yet to be broken.

WORLD MAJOR MOTOR SPORT
NASCAR
CATEGORY
Stock Car

N A S C A R

Where ordinary production cars become monster machines.

NASCAR is a stock car race based on modified production cars and, just like the IRL, it stands as one of America's major racing categories. Its roots are said to lie in the amateur automobile racing that took place in the central states of the USA during the early 20th century. Set apart from races held in Japan or Europe, this ultra-fast, quintessentially American race format takes place not on road courses, but on short oval circuits ranging from 0.5-mile (approx. 0.8-kilometer) to 2.66-mile (approx. 4.3-kilometre) superspeedways. Because the use of modern electronics and materials is prohibited, the cars vary little in performance, meaning that the excitement of the races relies almost entirely on the skills of the drivers.

WORLD MAJOR MOTOR SPORT
D1 Grand Prix
CATEGORY
Drift Car

D1 Grand Prix

Acrobatic driving and dramatic white smoke make for a spellbinding spectacle.

In the D1 Grand Prix, victory is decided by the coolness of "drifts", performed by intentionally sliding the car's rear wheels (or all four wheels). The competition involves a mixture of dynamic and acrobatic driving impossible in a typical race, screeching tyres and lots of smoke. The performance is judged on criteria totally outside the realms of normal racing, and nothing else lives up to the spectacle of this competition. The drifting skill of the top drivers could almost be called a form of art.

WORLD MAJOR MOTOR SPORT
Formula D
CATEGORY
Drift Car

Formula D

A drift contest spanning the full width of the American continent.

Formula Drift began in 2004, and is America's drifting championship series. Contests are held all across the US in states including California, Georgia, Illinois, North Carolina, and Washington, and drivers compete to show off their sensational driving and intricate technique. With Japanese drivers also taking part, the intensity rivals that of the Japanese D1GP.

WORLD MAJOR MOTOR SPORT
WRC
CATEGORY
Rally Car

W R C

An incredible competition of machines traversing every possible surface, over mud, gravel, tarmac and more.

Alongside F1 and WTCC, the WRC is another world championship in which an FIA title is up for grabs. Unlike circuit racing, it takes place on closed-off public roads, and drivers compete for the fastest total time over the contest segments, called Special Stages (SS). In addition to tarmac and gravel, ice, snow and other course conditions born of the host country's climate and topography make every race more captivating. Alongside the WRC, where drivers compete with vehicles specially produced for the competition, there is also the Junior World Rally Championship (JWRC), where drivers under 28 years old compete with 1600cc NA engine FF cars, and the Production Car World Rally Championship (PWRC), where drivers compete with Group N regulation vehicles with a narrow scope for modification.

WORLD MAJOR MOTOR SPORT
Rally Raid
CATEGORY
Cross Country

Rally Raid

Not just velocity, but resilience, is vital in this rally discipline which bids farewell to beaten trails.

Taking place on completely unmaintained paths across deserts, jungles, and mountains, Rally Raid has earned itself a reputation as the most unforgiving of all the rally pursuits. The ability of vehicles to withstand harsh environments is often more important than performance, and sports utility vehicles such as the Mitsubishi Shogun and Toyota Land Cruiser have consistently proved their worth in events such as the Paris to Dakar Rally.

WORLD MAJOR MOTOR SPORT
Pikes Peak
CATEGORY
Hill Climb

Pikes Peak

A demanding hill climb where not only rivals but the natural conditions can also stand in the way of success.

Taking place on Pikes Peak, 16 kilometres to the west of Colorado Springs on the eastern edge of the Rocky Mountains, the course of this hill climb ascends sharply from the starting point, which is 2,862 metres above sea level, to the summit, a further 1,439 metres above. Although drivers' skills and the performance of their vehicles play a huge role; the difference in elevation between the starting and finishing points means that changes in natural conditions such as atmospheric pressure and air temperature can often make the difference between victory and defeat.

ALL LINKS CLICKABLE

CHAPTER

02

Apex [The Gran Turismo® Exclusive Magazine]

Mechanism

Understanding Car Specs


AMG

Basic Specs
CHAPTER 2
Mechanism

Basic Specs

The characteristics and performance of different vehicles varies wildly depending on their intended use. When choosing a vehicle, it's important to understand the basic principles behind each of its specifications.

Dimensions

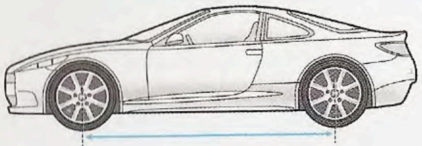
A vehicle's frame and the basic layout of its operating parts are the most basic specifications, and are decided during the initial stages of development, making them the hardest to change later on. These specifications have a crucial effect on the three main functions of driving, turning and braking. Any deficiencies are difficult to compensate for with tuning, and just a slight difference can have a huge effect on performance. Furthermore, the effects gained from tuning are also greatly affected by the car's base potential. To get the most out of your car, you should be familiar with how these basic specifications affect driving performance.

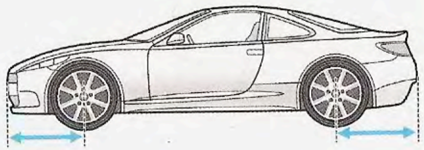
▸ Wheelbase

The wheelbase is the distance from the centre of the front wheels to the centre of the back wheels when viewing the car from the side. This length has a large impact on the stability of the car. The longer the wheelbase, the less affected the vehicle will be by undulation of the road surface and crosswinds, and it will tend to be more stable in a straight line. On the other hand, although a shorter wheelbase reduces stability, steering responsiveness is improved, and the car will be agile around corners. In terms of comfort, a longer wheelbase is generally considered better.

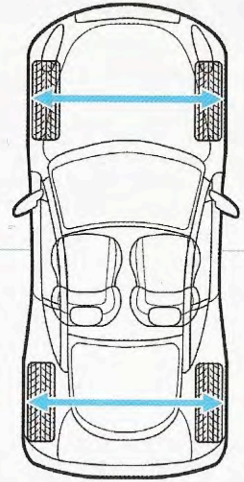
▸ Overhang

The front overhang is the length of the car that extends beyond the centre of the front wheels to the foremost end of the front bumper. Rear overhang is the length of the car that extends beyond the centre of the rear wheels to the end of the rear bumper. If the parts of the car on this overhang area are heavy, the yaw moment of inertia [resistance to turning] increases and manoeuvrability is reduced. Because of this, components of a car with significant weight should be placed within the wheelbase whenever possible. This is especially true for heavy components such as the engine. However, an overhang of some length is important for aerodynamic purposes, so it cannot be avoided altogether.





A car's performance is dependent on its dimensions and weight

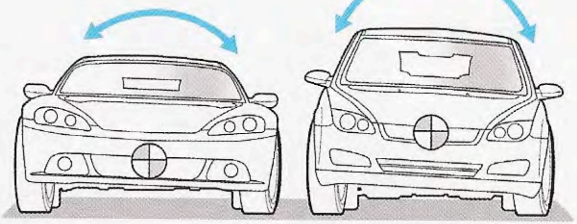


▸ Track Width

"Track width" refers to the distance between the left and right wheels of a car. Increasing track width will lower a vehicle's centre of gravity. Generally speaking, increasing track width improves traction when cornering, and increasing the track width of the drive wheels will increase contact with the road surface, and thereby improving the vehicle's ability to transfer its power to the road surface. A smaller track width, on the other hand, will offer quicker handling but will reduce stability. It's common for racing cars to have different track widths for the front and rear wheels so as to improve handling.

▸ Height

Height is measured from the road surface to the highest point of a vehicle. Lower height means a lower centre of gravity, reducing roll when cornering and increasing turning speed. However, lower height also means less room for passengers and shortened suspension stroke [the amount of room that suspension springs have in which to expand and contract], and increases the risk of bottoming out the suspension.



▸ Weight

Weight is a crucial factor in determining vehicle performance. The lighter the car, the less demand on the engine, and the more power can be used for movement. Other benefits include reduced brake wear and more efficient cornering. The weight of a car divided by its maximum power output is known as the power-to-weight ratio. The smaller this ratio, the faster acceleration will be, and the sportier the ride. This also has a major effect to fuel economy, and reducing the weight of a car is now an important factor in designing new cars in terms of environmental impact and performance.

Drivetrains and Weight Distribution

Like size and weight, drivetrain is another basic vehicle specification. Drivetrain specifications are pairs of letters that describe the location of the engine and the drive wheels in terms of "front", "middle" and "rear", with the engine location indicated first and drive wheels second. FF, FR, MR, and RR are some of the more common drivetrain specifications. This information is important because the location of the engine – the heaviest part of the car – and the wheels that it drives will have a huge effect on weight balance and movement.

In cars with good weight balance, the power of the engine will be effectively transmitted to the drive wheels, and will positively impact starting and acceleration. Braking at speed will also be more effective, as the car will pitch forward less.

But the most important benefit of good weight balance is improved cornering. Cars with poor weight balance can be destabilised more easily by centrifugal force and are at higher risk of spinning out of control.

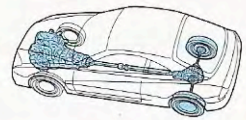
The ideal weight balance is 50:50 between front and rear, and left and right. In FR cars where the engine is at the front and the drive wheels are at the rear, this distribution is easily achieved. However, FF vehicles (and 4WD vehicles, which are often FF based), where the engine and drive wheels are at the front, will be front-heavy, and RR cars will be rear-heavy. Most FF cars now have their engines mounted transversely ("sideways" when compared to most vehicles) to try to improve weight distribution. However, hindrances due to weight balance are not impossible to resolve, and problems can be improved by tuning and driving to compensate for imbalances. It is subtle differences like these that mean an MR racing car would win against an FR car with good balance.

Manoeuvrability and basic structure

Types of Drivetrains

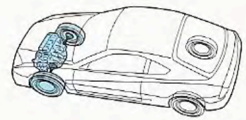
FR
► Front Engine, Rear-Wheel Drive

This is a conventional layout, with the engine located at the front and the drive wheels at the rear. An even weight distribution is easily achieved in vehicles with this layout. In addition to good handling characteristics, it has the advantage of having a good steering feel because the wheels used for steering (front) are separate from the drive wheels (rear). However, it can be difficult to gain traction (and thus drive power) on some surfaces.



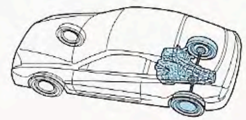
FF
► Front Engine, Front-Wheel Drive

A layout with both the engine and drive wheels at the front. Locating the heavy engine and transmission together in the front means that the cabin can be bigger, but inevitably results in a front-heavy weight-balance. Also, as the front wheels manage both drive power and steering, the grip of the front tyres is divided between maintaining forward movement and turning when cornering. Because of these reasons, this layout is relatively unsuited for high-powered vehicles.



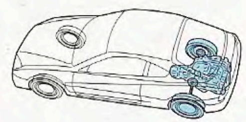
MR
► Mid-Engine, Rear-Wheel Drive

A layout with the engine located in the middle of the car, powering the rear wheels. Mounting the engine near the centre of the car makes it closer to the car's centre of gravity, which makes sharper cornering possible. It also ensures maximum grip in the front and rear tyres during acceleration and deceleration. This layout is a popular choice in sports and racing cars built for speed.



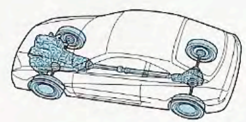
RR
► Rear Engine, Rear-Wheel Drive

A rear-wheel drive layout with the engine mounted in the rear overhang behind the wheels. This layout focuses the weight in the rear of the vehicle, pushing the rear wheels down onto the road surface and thereby improving traction and acceleration. However, it reduces load on the front wheels, making it easy to understeer when first entering a corner. Also, as there is so much weight on the rear wheels, if the rear end slips out it does so violently, and requires a high level of driving skill to recover.



4WD
► Four-Wheel Drive

A configuration where power is delivered to all four wheels. Despite the increased weight, this layout is the best-suited for standing starts and acceleration. However, its extremely high stability can cause it to be difficult to turn. It is possible to make all drive layouts into four-wheel drives, but the control of the vehicle will be greatly influenced by the drivetrain layout on which it is based. Generally, either the front or rear wheels will be considered the "main" drive wheels, and more torque will be delivered to the opposite wheels if the "main" wheels slip.



Engine
CHAPTER 2
Mechanism

The Heart of the Automobile

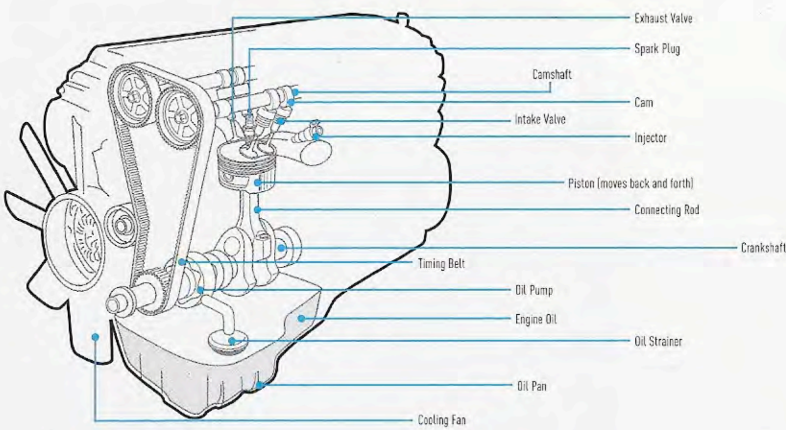
The engine is at the heart of a car. Understanding the engine and how it works is the key to getting 100% out of a vehicle.

Mechanism and Principles

Most cars are equipped with a four-stroke cycle reciprocating engine. Reciprocating engines are made up of cylinders within which pistons move back and forth to create energy. The four strokes of the engine are intake, compression, power and exhaust.

Let's take a closer look at these four strokes of the cycle. In the intake stroke, the intake valve opens just before the piston reaches "top dead centre" – the position where the piston is at the top of the cylinder. When the piston starts to go back down, an air-fuel mixture is drawn in through the open valve. When the piston reaches the bottom of the cylinder, the intake cycle is complete, and the compression cycle, during which all the valves close and the rising piston compresses the air and fuel in the cylinder, begins.

Just after the piston has reached the top of the cylinder compressing the air-fuel mixture, the spark plug is ignited, causing the fuel-air mixture to explode. This is the power stroke, at which point the inside of the cylinder can reach temperatures of up to 2000°C, and pressures of up to 200 atmospheres. This high temperature, high pressure combustion force pushes the piston back down, turning the crankshaft, and in effect converting thermal energy into mechanical (rotational) energy. When the piston reaches the bottom again, the exhaust stroke begins, and the exhaust valves open so that the left-over gases can be discharged. These gases are not discharged by the motion of the piston, but are mostly discharged by their own heat and pressure, which causes them to fly out through the valves. Once the piston reaches the top again, the intake valves open, and the cycle begins afresh. A reciprocating engine runs through these four stroke cycles and turns the crankshaft at several hundred times a minute when idling, and several thousands of times per minute at high speeds, to continue creating power for the car.

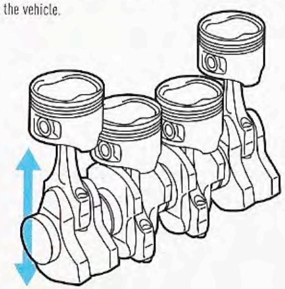


How does an engine work?

Types of Cylinder Configurations

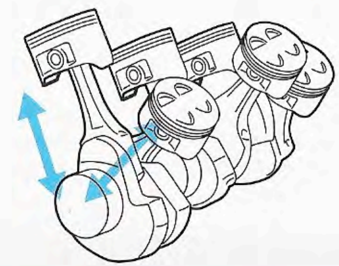
In-Line Engine

Multiple cylinders are aligned in a single row. All cylinders share one crank shaft and the cylinder block is made up of a single piece, so construction is simple and the engine can be relatively lightweight. However, the more cylinders there are, the longer the engine will become, which starts to become a hindrance as more space is required within the vehicle.



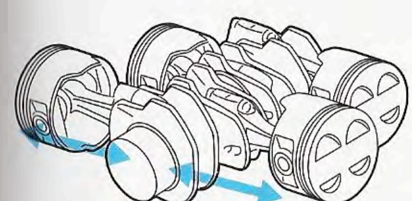
V Engine

Right and left alternating cylinders mounted in a V-shape. The crank shaft can be made shorter, and has the advantage of being compact with even a large number of cylinders. Regardless of the number of cylinders, there is little vibration, and the short cylinder block and crankshaft are superior in terms of rigidity.



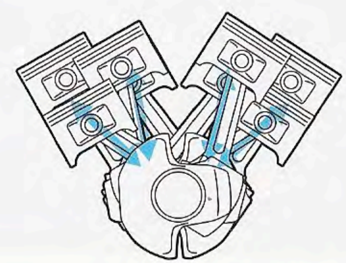
Flat Engine

Alternating cylinders arranged horizontally. The right and left cylinders are horizontally opposed with the crank shaft in the middle. These are sometime called "boxer" engines, because the pistons moving left and right resemble the jabs of a boxer. The benefit of this engine is its low centre of gravity due to its reduced height.



W Engine

This used to refer to an engine with a single crankshaft with three lines of cylinders fanned out in the shape of a W, but in recent years engines with two narrow angle V engines joined together is also called a W engine. The width of the W engine is greater than that of the V engine, but its shorter crankshaft makes it more advantageous in engines of 12 cylinders or more.



Valve Configuration

In a four-stroke engine there are two types of valves: the intake valves that open during the intake stroke, allowing the air-fuel mix into the engine, and the exhaust valves that open during the exhaust stroke, releasing waste gases. The valves are located in the cylinder head and play an important role in connecting and blocking off the combustion chamber.

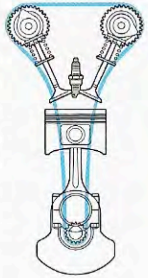
Modern engines typically have the camshaft at the top of the engine, which allows more reliable valve movement. Most modern engines have 4 valves per cylinder with 2 intake valves and 2 exhaust valves, but engines that focus on combustion efficiency at the low RPM range with 2 valves per cylinder, consisting of 1 intake and 1 exhaust valve, will probably be making a comeback in the future.

The latest trend is towards variable valve timing. Initially, this allowed valves to have two timings - one for low revs, and one for high revs - but more recent developments allow valve timing and lift to be varied continuously to match the engines' revs. In the latest variable valve mechanism of the "Valvetronic" BMW engine, power adjustment is accomplished without using the throttle valve, achieving greater efficiency.

Types of Valve Configuration

DOHC

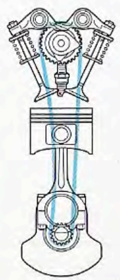
▶ Double Overhead Camshaft



DOHC stands for Double Overhead Camshaft. In a DOHC engine, one camshaft operates the intake valves and one camshaft operates the exhaust valves. Other than ensuring stable operation by sharing the work over two camshafts, it also means that there is less reciprocating mass (inertia) in the valvetrain, and this makes it possible to achieve higher RPMs with the engine. This in turn allows better power output, which is why this layout has been adopted in most of today's high-performance engines.

SOHC

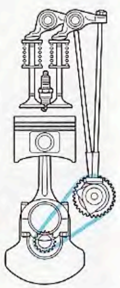
▶ Single Overhead Camshaft



A single overhead camshaft is an engine with a single camshaft operating the exhaust and intake valves. Depending on the type of combustion chamber, the camshaft can either directly operate the valves, or it can operate the valves through rocker arms. Compared to an OHV engine, valve movements are more reliable, and higher revs are possible. Compared to a DOHC engine, valve movements are not as smooth, but high RPM SOHC engines exist, so they are not always inferior.

OHV

▶ Overhead Valve



An overhead valve is, as its name suggests, a system where the valves are mounted on the cylinder head. Unlike an SOHC or DOHC setup, the camshaft is located to the side of the cylinders and the camshaft operates the valves with long arms called "pushrods". This structure is simple and is easily maintained. However, valve operations in these types of engines are not as reliable at high RPM, and are not generally suited for high power.

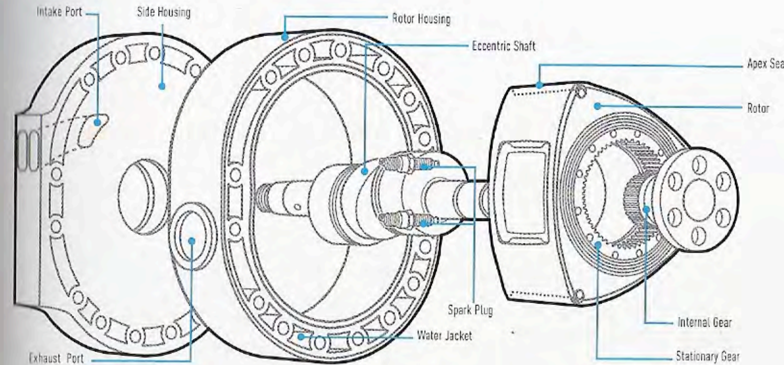
Rotary Engines

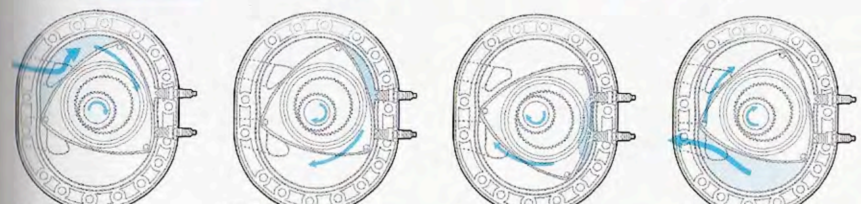
Rotary engines (also known as Wankel engines) produce power in a manner similar to reciprocating engines in that they go through the four stages of intake, compression, power and exhaust. However, these processes are performed in a very different way.

Instead of cylinders, this type of engine has a cocoon-shaped (epitrochoid) rotor housing, within which sits a triangular rotor. This rotor orbits the eccentric shaft within the housing, which expands and contracts the spaces between itself and the housing, and it is in these spaces that intake, compression, power and exhaust cycles are carried out. A rotary engine will usually consist of two or three of these rotors moving within an equal number of rotor housings.

In typical engines, the reciprocating movement of multiple pistons makes smooth power control difficult and also produces a lot of noise and vibration. However, since rotary engines are based on rotational movement, the operation of the engine is much smoother. Another benefit of this type of engine is its lack of valves, which greatly reduces the number of parts. Rotary engines also used to be significantly lighter, and although advances in reciprocating engine technology have reduced this difference, rotary engines are still the more compact of the two designs.

The timing of the intake and exhaust processes in a rotary engine is dictated by the shape and positioning of the ports (the channels through which the gases move in and out) in the rotor housing wall. Tuning a rotary engine's intake and exhaust is a matter of changing the shape and position of these ports. Also, as rotary engines have no exhaust valve, and exhaust gases are emitted directly through the exhaust port with no interference, they work well with turbochargers. Compared to a reciprocating engine, a rotary engine is at a disadvantage in terms of fuel consumption. This is due to the relatively large surface area in relation to the combustion chamber capacity, which causes increased heat loss and lower efficiency in converting thermal energy to mechanical energy.





Forced Induction

An increase in the amount of air flowing into an engine will result in an increase in power. The simplest way of achieving this is by increasing engine displacement. However, it is also possible to achieve a similar effect without altering displacement, through a process known as "forced induction". This involves forcing more air into the engine through compression. Devices that perform this process are separated into two categories: superchargers and turbochargers.

The amount of pressure added when the air is compressed is known as the "boost", and the more boost, the more power can be achieved. One atmospheric pressure is known as one bar, or 1kg/c of air.

If the boost is 1 bar, this makes a total of 2 bars of atmospheric pressure (1 bar of natural air pressure plus 1 bar of boost) of air entering the engine, which is double the normal amount. The problem with forced induction is that as pressure increases, combustion energy also increases, which can cause damage to the engine.

For this reason, the internal parts of engines with turbochargers and superchargers are usually reinforced, and the compression ratio lowered to solve the problem of improper combustion. When air is compressed, its temperature is increased, and its density lowered. This effect is even more pronounced under intensive driving conditions or in hot weather, and prevents the engine from achieving maximum output power.

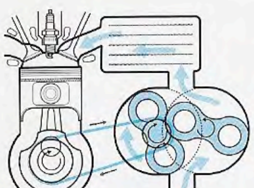
It is said that a one-degree increase in temperature causes a loss of approximately 1 horse power, so it is normal to include an intercooler device to cool the compressed air. Turbochargers take time to kick in, as their forced induction is powered by exhaust energy and there is a time lag until the boost pressure rises.

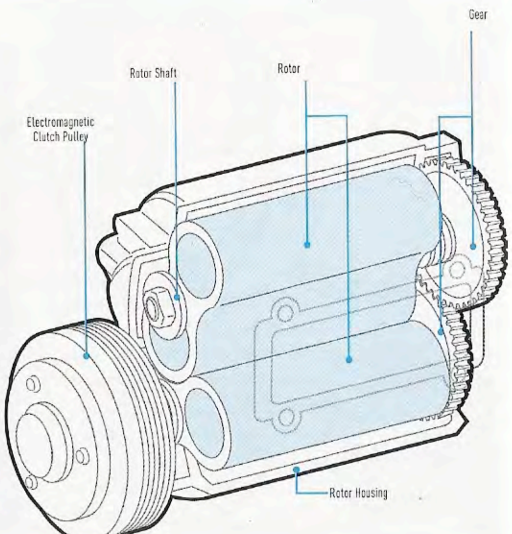
On the other hand, superchargers powered by the engine crankshaft do not suffer this delay, but they do sap a small amount of power from the engine because they are driven by the crankshaft. Engines that harness the merits of both setups by utilising a supercharger for low revs and a turbocharger for high revs have recently started to attract a lot of interest.

▶ Superchargers

A supercharger is a compressor, usually powered by a belt attached to the crankshaft, that compresses air before it is introduced to the engine. Because the compressor is powered by the rotation of the crankshaft, it has a high supercharging effect at low RPM and accelerator response is better compared to a turbocharger.

A supercharger also tends to work well in cars with automatic transmission. The illustration here is of what is known as a "roots blower", but several other types of supercharger exist, including Lysholm compressors and scroll-types.

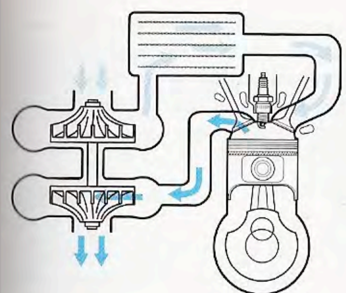


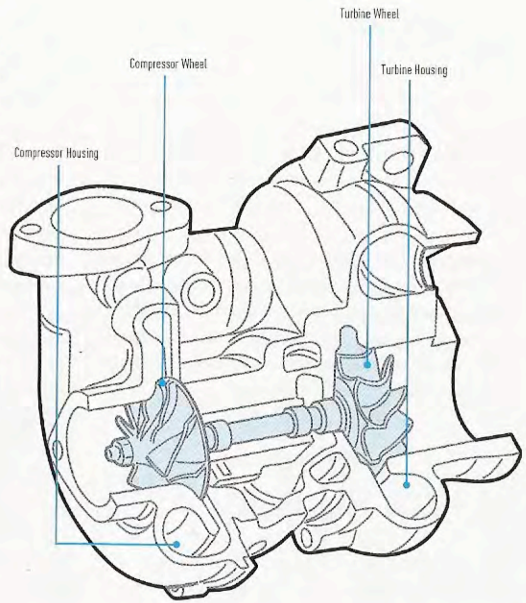


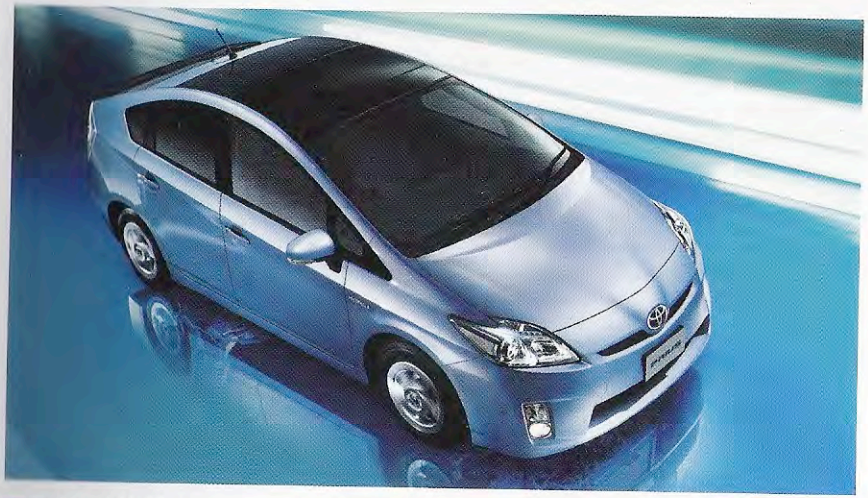
Achieving the same effect as increased displacement

▶ Turbochargers

Named "turbo" due to the turbine which powers its compressor. A turbocharger uses the gases released through the exhaust pipe to turn its turbine. Because it uses the energy from the exhaust gases, there is no power loss at high revs as there would be with a supercharger. However, at low RPM's there is less exhaust gas produced, the turbine will not turn at operating speed and it takes time for the turbine to spool (speed up) when accelerating. This momentary delay in response is known as "turbo lag". A variety of systems have been devised to compensate for this and they are still continuing to evolve. In Europe, turbochargers are increasingly being used for smaller engines for improved fuel economy.







Driving using both engine and motor

Hybrid Systems

The purpose of a hybrid system is to increase fuel economy by using both an engine and an electric motor. Japan has been the leader in hybrid car development, and although these hybrid systems have been known mainly for their environmental benefits, European sports car makers have begun to develop some with the potential to power a new generation of high-performance vehicles.

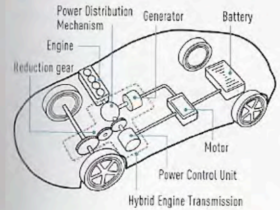
The weakness of an internal combustion engine is its inefficiency when idling and accelerating from a standstill. On the other hand, an electric motor can generate maximum torque at almost zero revolutions and because of its high efficiency, can compensate for the poor performance of an engine at low revs. A combustion engine is still more efficient at speed, so the overall efficiency of the hybrid car is achieved by combining the strengths of both systems.

Another advantage of having an electric motor and a battery is that a hybrid system also benefits from the ability to recover energy. When decelerating by taking your foot off the pedal or when braking, the motor acts as a generator driven by the rotation of the wheels, which recharges the battery. This energy can then be reused afterwards to power the motor. In this way, the energy usually wasted as heat when braking can be reused to generate electricity instead. Another benefit is that the motor can be made to behave like a supercharger for the engine. Many hybrids made by European manufacturers actually place emphasis in this direction, achieving the driving feel of a high displacement engine (with a small displacement engine) by adding electric motors rather than supercharging.

Hybrid systems and their merits differ depending on how the motor and the engine are made to work together. There are now several types of hybrid systems in commercial use, but the variety will probably continue to grow. Hybrid engines for supercars are currently under development, and it will be interesting to see what kind of system will come into use in the future.

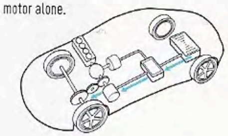
The Toyota Prius

▶ System Overview



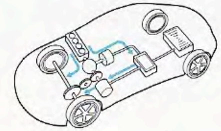
▶ When Accelerating from Standstill or at Low/Medium Speeds

When accelerating from a standstill or driving from low speed to medium speeds, the engine is not efficient and is stopped. Drive power is provided by the motor alone.



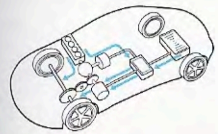
▶ Normal Driving

Engine power is divided into two systems by the power distribution mechanism, one for driving the generator and one for directly driving the wheels.



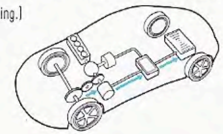
▶ Rapid Acceleration

Boosted by the battery. Drive power from both the engine and the motor combines, resulting in good response and smooth acceleration.



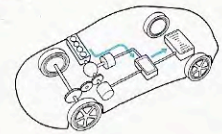
▶ Deceleration & Braking

The wheels drive the motor, which functions as a generator, efficiently transforming the braking energy of the car into electricity, which is used to recharge the battery. (Also called regenerative braking.)



▶ Battery Charging

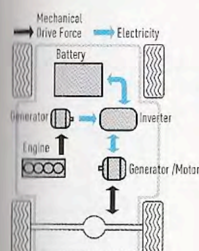
The battery is designed to maintain a constant level of charge. When the battery is low on charge, the engine will start up, drive the generator and recharge the battery.



Types of Hybrid System

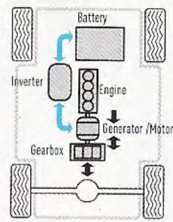
▶ Series Hybrid

The role of the engine is solely to turn the generator, and only the motor propels the car. This system is simple, and the engine can be located wherever desired. This is basically an electric car with a generator.



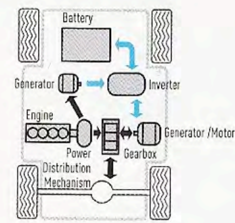
▶ Parallel Hybrid

The engine and the motor work in parallel. The motor is usually located between the engine and the transmission, resulting in high productivity. The downsized engine still plays the major role in providing drive force, and the aim of the motor is to assist the engine, in an attempt to combine drive performance and fuel efficiency.



▶ Series-Parallel Hybrid

Also known as a power-split hybrid. The power distribution mechanism uses a planetary gear to divide power between the generator and the motor. At initial acceleration and at low speeds the battery provides the power, while during normal driving conditions the engine runs as efficiently at the efficient RPM range while running the generator and charging the battery.



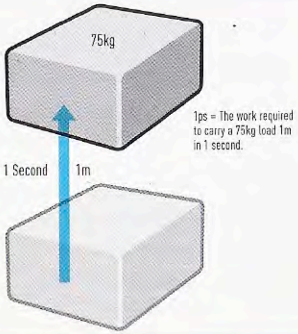
Performance Keywords

When looking at a vehicle's catalogue specifications, you'll be presented with a whole host of numbers and specialist terms. It is important to have a good grasp of these in order to really understand a car's characteristics and potential.

There are five basic terms that define an engine's potential. You may think you are familiar with terms such as "horsepower" and "torque", but let's take a closer look at them so we can really understand what they mean for a vehicle's performance.

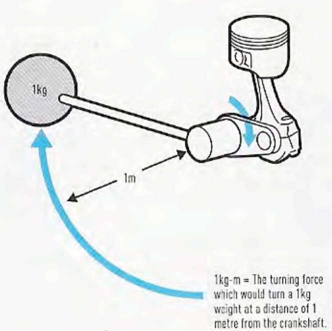
▶ Horsepower

Horsepower represents the upper limit of the engine's ability, and is usually measured in units called "ps" or "HP". One horsepower represents the engine's ability to carry a 75kg load 1 metre in 1 second. In other words, a 100 horsepower engine could carry 1 tonne 7.5 metres in 1 second at maximum power. Horsepower is calculated by multiplying torque by engine revolutions, so a low-displacement engine can still provide a large amount of output power if high enough revs can be achieved. Internationally, horsepower is also sometimes listed in kW (1PS=0.735kW).



▶ Torque

Torque is a measure of turning force. For example, using 1kg of force to turn a nut with a metre-long spanner would be exerting a turning force or torque of 1kg-m. In terms of engines, torque describes the strength of the force acting to turn the crankshaft. The higher the torque, the stronger the power maintaining the engine revs, and the easier the driver will find it to control the engine.



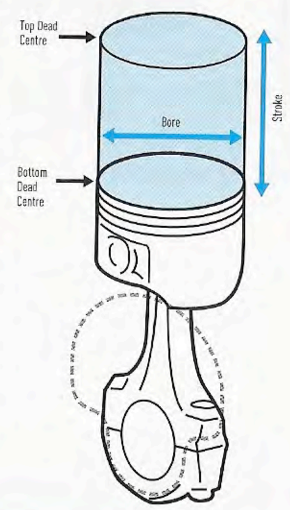
▶ Displacement/Number of Cylinders

Displacement describes the volume of air-fuel mixture drawn into an engine. In a reciprocating engine, this is calculated by multiplying the volume of the cylinders where the piston reciprocates by the number of cylinders. The more displacement, the greater the output power, but the larger the volume of a single cylinder, the less smoothly it will turn the engine. That is why the number of cylinders is increased to keep the volume per cylinder low. Also, increasing the number of cylinders also increases the number of combustion cycles per 1 rotation of the crankshaft, and the revolution of the engine becomes smoother.

Generally speaking, a cylinder's displacement should be between 350cc and 600cc. However, engines with a large numbers of cylinders are more expensive, so cylinder size is generally dictated by the size and class of the vehicle.

▶ Bore/Stroke Ratio

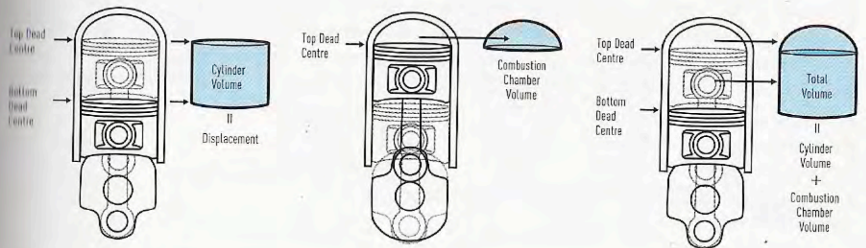
The bore/stroke ratio is the relationship between the diameter of the cylinder and the length of the piston's movement within the cylinder. Engines with a ratio of less than 1:1 are known as "short-stroke" engines, while those with a ratio of more than 1:1 are "long-stroke". A ratio of exactly 1:1 is known as "square". The size of the bore/stroke ratio affects how the engine behaves. Generally speaking, a long-stroke engine can produce torque at low to medium revs, but power at high revs is harder to achieve, while the opposite is a true for a short-stroke engine. It is also useful to know that when the piston is at the very top of the cylinder, this is called "top dead centre". And when at the bottom of the cylinder, the condition is called "bottom dead centre".



▶ Compression Ratio

The compression ratio describes how much the air-fuel mixture drawn into the engine is compressed. Engine power is greatly influenced by compression ratio. The compression ratio is calculated by dividing the volume of the cylinder when fully open ("total cylinder volume") by its volume when fully closed ("combustion chamber volume"). Total cylinder volume is the displacement plus the combustion chamber volume.

For example, in a 2000cc, 4-cylinder engine, displacement per cylinder is 500cc. If the combustion chamber volume is 50cc, the total cylinder volume is 550cc. 550cc divided by the combustion chamber volume (50cc) gives a compression ratio of 11. Typically, naturally-aspirated engines have a compression ratio of between 9 and 11. Compression ratios of over 10 produce high output for the amount of displacement. Engines with forced induction devices generally have compression ratios of between 7 and 9.



Drivetrain
CHAPTER 02
Mechanism

The Drivetrain - Turning Power into Speed

Gearing and traction are necessary to turn power into speed.
The parts of the drivetrain have a massive impact on driving performance.

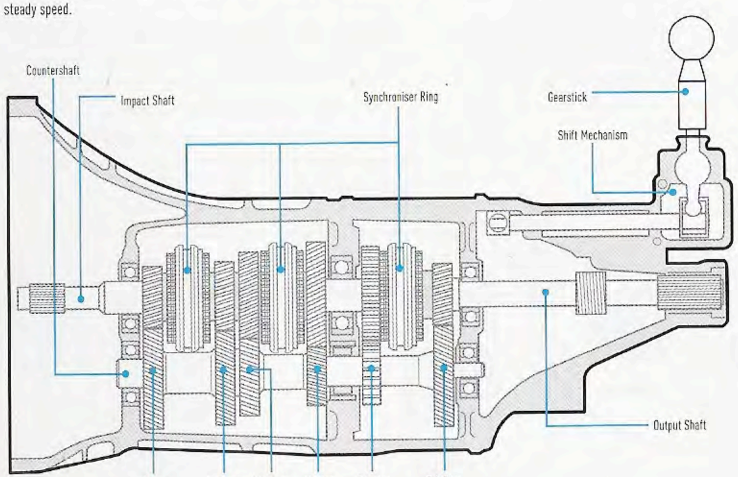
Transmission

An engine revolves at anywhere between several hundred and several thousand times a minute. This would be too fast to turn the wheels directly, so an intermediate mechanism is needed. This is where the transmission comes in. The transmission uses different gears to transmit the appropriate amount of power and speed to the wheels for any given situation.

Let's look at how gears work. If a small gear is driving a larger gear, the larger gear will rotate slowly, but its torque will be increased. Conversely, if a large gear is driving a smaller gear, the small gear will turn faster, but with less torque. The transmission can make use of these principles to fit the appropriate gear to the appropriate situation. A car needs most power when accelerating from a standstill and, conversely, only needs a small amount of power to maintain a steady speed.

Thus, when accelerating from zero, a large gear (with slow rotation but high power) is used to transmit enough power to set the car in motion. A large gear will create a lot of torque, but will rotate slowly. This means that in first gear, even revving to the limit will only produce speeds of several tens of kilometres per hour. This is why several gears are used, gradually getting smaller as the driver shifts up and producing more speed and less torque. The ability to move freely between these gears allows the driver to use the right gear for the right situation.

On an actual car, in addition to these gears of these transmission which are connected directly to the engine, the overall gear ratio is determined by combining with another "final gear" that is between the transmission and the drive wheels. The gear ratio can greatly affect the driving characteristics of a car and especially in circuit racing, the selection of the proper gears suited for the course will be a major key in improving your lap time.

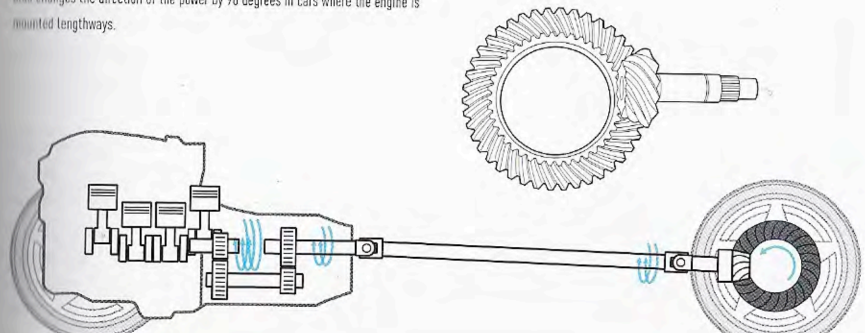


Efficiently harnessing drive power

The Final Gear

The gear that mediates the final transmission of power from the engine to the drive wheels is known as the "final gear". It is the last step in the chain which brings engine revolutions down to an appropriate speed to power the wheels, and also changes the direction of the power by 90 degrees in cars where the engine is mounted lengthways.

The final gear is independent of the transmission, and replacing it is a simple and often extremely effective way of adjusting how a car behaves. In sports cars, the gear ratio of the final gear is usually large to improve acceleration performance, but if the focus is on fuel economy, a smaller ratio can be used to reduce overall revs.



Types of Two-Pedal Transmission

AT

▶ Automatic Transmission

A common transmission that uses a torque converter (a type of fluid coupling) to automatically change gear based on speed and engine RPM. The system uses planetary gears controlled by hydraulic pressure. Has the advantage of smooth transition between gears, but the hydraulic slippage and loss due to the mechanism causes poor fuel economy.

CVT

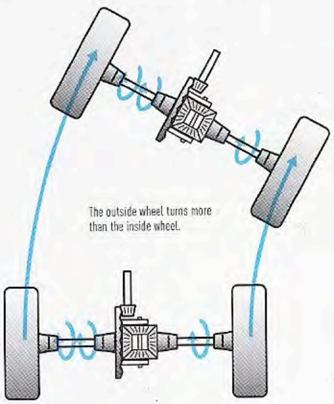
▶ Continuously Variable Transmission

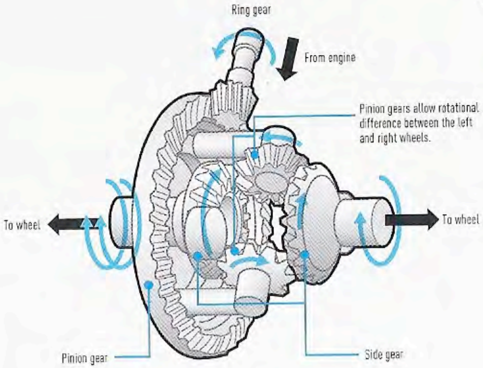
A continuously variable transmission does not change through gears one-by-one like a normal transmission. Instead, it uses two pulleys or discs connected by a metal belt or chain, to seamlessly and continuously vary the gear ratio. It is extremely smooth, producing no shock from gearchanging, and allows the engine to run at peak efficiency under almost any conditions.

DCT

▶ Dual-Clutch Transmission

A dual-clutch transmission is basically a system in which the operations of a manual transmission have been automated by the use of two clutches. Odd and even gears are separated onto two shafts, and by instantly switching between them with the clutch, it shows shifting performance that exceeds that of manual transmissions. In the AT, the rotational limit of the planetary gear places a restriction on the maximum RPM of the engine, but the DCT is compatible with high RPM engines. This is a transmission system that will continue to grow hereafter, being suited for both sportscars and eco cars. (see also "DSG" on page 117).





Differential

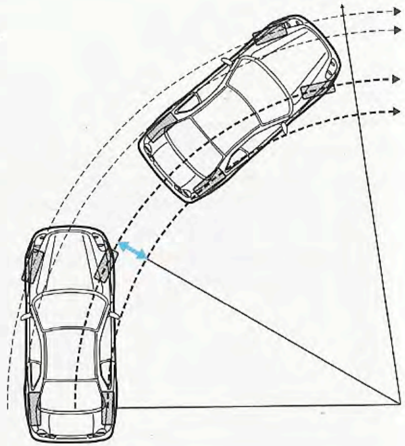
A differential is absolutely essential in vehicles with drive wheels on both the left and right sides. If we only ever drove in straight lines, differentials would not be necessary, but as soon as a car turns a corner, the need for one becomes very clear.

When cornering, the wheels on the outside of the corner have to travel further than the wheels on the inside. If the inside and outside drive wheels cannot be driven at different speeds when this happens, the inner wheel will resist and skid and the car will find it difficult to turn. The differential is a type of gear, integrated with the final gear, set between the drive wheels in order to solve this problem.

Take a look at the diagram above-right. Engine power is transmitted through the final gear to the ring gear. The ring gear has two pinion gears fixed to it which turn the two adjacent side gears, and these gears transfer the power to the left and right wheels.

When the car is moving in a straight line, the rotation of the final gear operates the ring gear, turning the pinion gears and is transmitting power evenly to both of the side gears. Here, both the left and right wheels turn at the same speed.

However, when cornering, resistance is generated by the wheel on the inside of the corner and this is transmitted to the corresponding side gear. When this happens, the pinion gears, which were revolving evenly with the side gears without turning, will begin to turn to allow a difference in rotation speed to develop between the left and right wheels. This means that slightly less power will be delivered to the wheel encountering resistance on the inside of the turn, and slightly more to the wheel travelling further on the outside, and each wheel will turn at the correct speed to negotiate the corner.



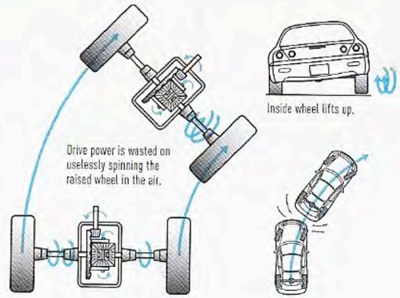
Smooth, solid cornering

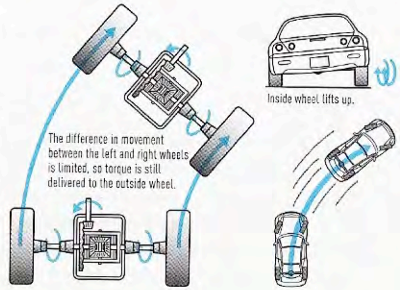
Limited-Slip Differential

We just went over the role of a differential in a corner, but they have one disadvantage. If one drive wheel loses contact completely with the road surface, the other drive wheel will not receive any drive power, and the wheel that is not in contact with the ground will spin wildly. This is because the differential is trying to correct the difference in rotation by transferring all the drive force to this one wheel. This phenomenon can also be seen in cars stuck in ice or snow, where the complete loss of traction on a single drive wheel again causes that wheel alone to spin uselessly.

A limited-slip differential (LSD) is a system that is designed to suppress the function of a differential when there is more than a certain amount of difference in rotation speed between the right and left drive wheels.

The idea of an LSD is to ensure that the correct amount of drive power is distributed between the drive wheels by using a device to limit the difference in turning speed between the two side gears. There are several ways of achieving this, including multi-clutch systems electrically controlled systems and systems that rely on friction acting in viscous fluids. In sports cars, LSDs are used not so much for escaping mud and snowy pot holes, but to ensure effective use of drive power and improve handling.





Types of LSD

▶ Torque-Sensitive Type

A system that employs specially designed gears. When a difference in torque arises between the left and right wheels, resistance increases between these gears, limiting the amount of difference that can occur. As these systems can place strict limits on drive-wheel speed difference, they are effective in demanding driving situations such as circuit driving and their response time is also very short. There are several types of torque-sensitive LSD, including multi-gear, Torsen and helical.

▶ Speed-Sensitive Type

These systems generally restrict the differential using a highly viscous silicon oil rather than gears. The most common system of this type is the viscous-type, which uses the shearing resistance of the oil, but there are also so-called "orifice-type" systems that use the resistance of oil moving through small orifices. These systems cannot restrict movement as well as the torque-sensitive types and their response is not as good, but they are easier to control on low-traction surfaces.

▶ Active-Control Type

Electronically controlled systems that use a computer to gather and collate information from sensors and control the difference in drive-wheel rotation. Many competition racecars, particularly rally cars in the WRC, use these systems, and some commercial vehicles have also adopted them. Limitation of the differential's operation is controlled by friction plate pressure, using a hydraulic or electromagnetic clutch.

Body

CHAPTER 02
Mechanism

The Framework that Supports it All

A car's body shape and construction can affect its performance just as much as its engine and transmission. This is the foundation that determines good or bad control.

Body Performance Requirements

Along with the engine and suspension, the body makes up the basic framework that dictates how a car will behave. The most desirable qualities in the body of a car are rigidity, strength and, once these have been established, a lightweight construction. The best way to think of rigidity and strength is in terms of "resilience against deformation" and "resilience against breakage" respectively.

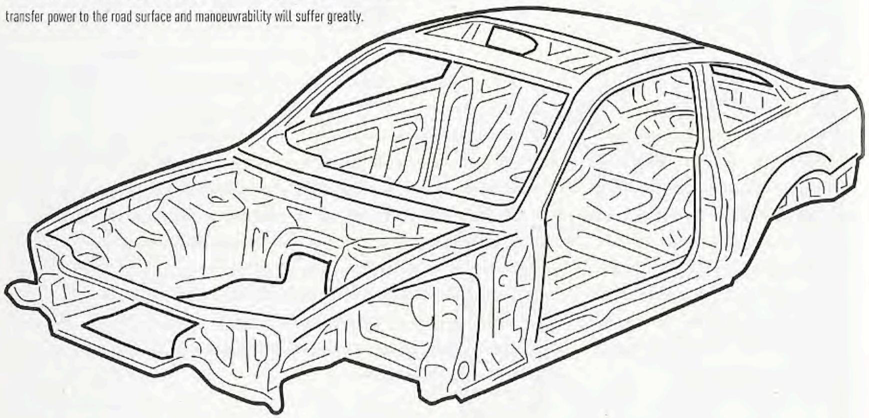
Rigidity has a particularly strong influence on driving performance. For example, when load increases or shifts while driving on a bumpy road or cornering, a rigid body will not bend or change shape as a result.

Even if the body shape does change, it should return to its original shape immediately so that the suspension can operate normally and the tyres can continue to grip the road. The more rigid a car's body, the easier it is to transmit power to the road surface, the more predictable the car's behaviour will be and the easier the car will be to drive. Conversely, if the body deforms easily, it will be more difficult to transfer power to the road surface and manoeuvrability will suffer greatly.

The forces acting on the body of a car are not constant. There are those that have a slow and gradual effect and those that impact suddenly and violently. Cars are often described in their publicity material as having good rigidity when turning or under torsion, but this usually means only when these forces are applied slowly. A truly rigid body should be able to sustain sudden impact from any of the forces that may act upon it.

Strength can be thought of as a car's toughness. If a car with low strength takes an impact, it will sustain heavier damage. However, it is not enough just to minimise damage - a car with high strength must be built in such a way that the shock of an impact is not transferred to the passengers.

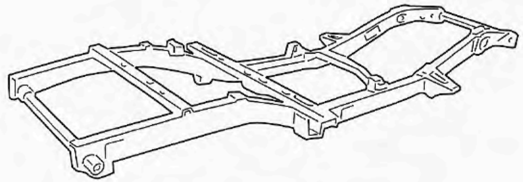
Ideally, a car's body should have a good balance of high rigidity and strength. The easiest way to increase both of these qualities is through reinforcement, but then an increase in weight becomes unavoidable. This is the major reason why convertible cars without roofs actually become heavier than closed top cars, as their floors are reinforced.

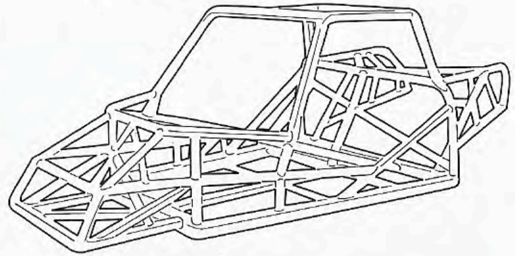


Strength and rigidity

Body-on-Frame

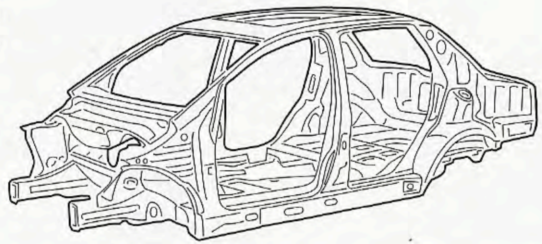
In separate frame or body-on-frame types, the engine, transmission, suspension etc. are fixed to a frame and then a separately manufactured body is attached. There are various frame designs, including ladder, backbone, perimeter and platform, but ladder frames are the cheapest and also the easiest to strengthen, and are therefore the most common, particularly in off-road vehicles. Another type of body-on-frame design is created by welding lots of small pipes together to make a frame to which panels can then be attached. This is known as a multi-tubular frame, and cannot be disassembled once built. However, it is easier to achieve high rigidity and a lightweight body with this type of frame, and modification and repairs are simple, so this construction is often adopted for racing cars or low-volume production sports cars.





Monocoque Body

This is the most common body type in modern vehicles where the frame and body are combined. The strength of the body is created through the entire assortment of parts like the component body panels, and is lightweight and rigid. It also has an advantage in that the floor height can be lowered and it is excellent at absorbing energy in an impact. The fact that the engine and suspension are directly attached to the body initially caused problems with ride quality and noise, but advances in suspension and engine-mounting technology have made these problems a thing of the past.



Brakes
CHAPTER 02
Mechanism

Brakes – Thermal Exchangers that Reduce Speed

A car's brakes turn drive energy into heat energy in order to decelerate. Not only must they have stopping power, these essential components must also be able to dissipate heat effectively.

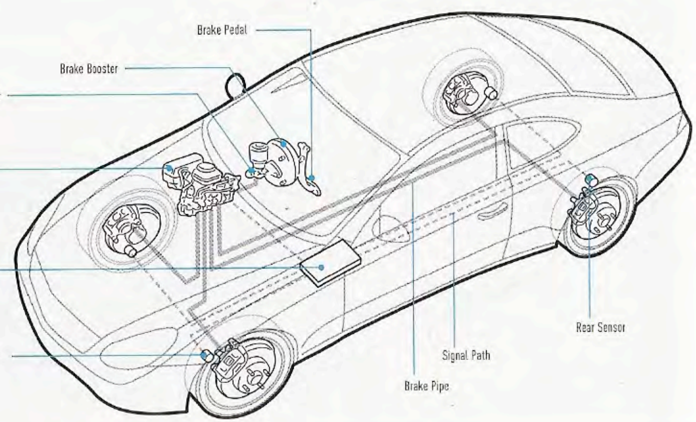
Construction and Principles

A car's brakes turn kinetic energy into heat energy to achieve deceleration. The brakes are also responsible for ensuring a car doesn't move when parked. The basic components of a brake system include a control device which takes the input from the driver, a hydraulic system that relays the control operation and the actual braking device. Recently, this process has been improved with the introduction of control mechanisms that multiply driver input to increase braking power, and ABS systems that stop the wheels from locking up.

The brake pedal and the brakes are connected via a hydraulic line. Since the Pascal principle applies to a hydraulic line, the brake pedal is connected to a large cylinder. The pressure built up at this cylinder is boosted and sent to the brake pad or brake shoes. The pads and shoes are made of high friction materials and by pressing these against the brake disc or brake drum, kinetic energy is converted into thermal entergy, thereby slowing the car down.

The fluid used in the hydraulic line is not oil and is a specialised fluid made for brakes. Brake fluids must not boil when exposed to the heat of the brakes, and there are various types of brake fluids with various boiling temperatures available. As motorway driving has become more common, the front brakes of most road cars have moved from drum to disc brakes. In a disc brake system, braking force is applied on both sides of the brake discs by the brake pads that are supported by the calliper.

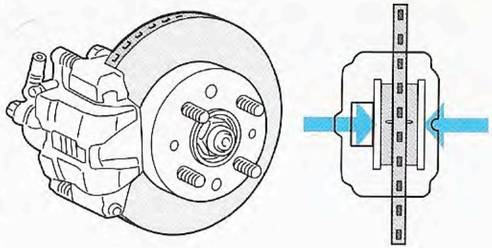
Disc brakes have advanced along with other car technologies, and ventilated discs with improved cooling properties have been developed. Calliper technology has also improved, with traditional floating callipers being replaced by large, high performance opposed-piston callipers.



What makes a car stop?

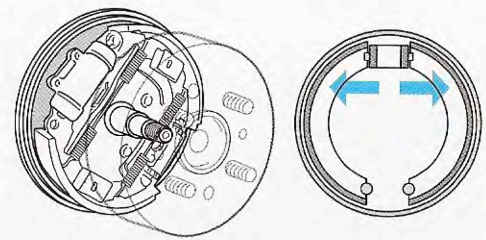
Disc Brakes

Friction is applied to both sides of a metal disc that turns with the wheels. Their major advantage is that because most of the components, including the disc itself, are exposed to the elements, ventilation and heat dispersion are excellent, making them less prone to overheating. Another benefit of disc brakes is that if they get wet, the water will naturally disperse as the wheel turns and there will be no significant friction loss. It is easier to perform sensitive control of the brakes through the brake pedal with disc brakes, but the brakes do not multiply their own braking power as in a drum brake, and holding ability when parked is less than that of a drum brake.



Drum Brakes

Braking is performed by pushing brake shoes against the inside of a cylindrical drum that turns with the wheels. Heat dispersion is poor, and overheating occurs much more easily than in disc brakes. Also, if water enters the drum, it takes time to recover friction. However when braking, the rotation of the drum automatically drags the shoes against the friction surface, causing the shoes to bite more and producing additional braking force. In passenger cars, it is normal for drum brakes to be fitted to the rear wheels, which take less of the braking burden. In larger vehicles, drum brakes are often mounted inside disc brakes on the rear wheels to act as a parking brake.



Braking Problems Caused by Excessive Heat

Fade

Fading is a reduction in braking force caused by overuse of the brakes. The pads or lining overheat and release gas, which acts as a sort of lubricant and reduces friction.

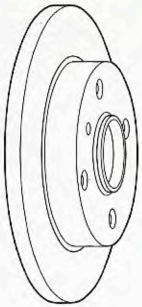
Vapour Lock

This is a condition in which the brake fluid has absorbed the heat from overheating pads or brake lining and has boiled, creating air bubbles in the brake line. When the brake pedal is pushed, the pressure isn't passed effectively through the fluid and, in the worst case scenario, the brakes will fail to work completely.

Types of Brake Disc

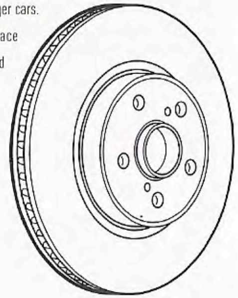
▶ Solid Discs

This is the most basic type, consisting of a simple metal disc. Heat dispersion is inferior to that of ventilated discs, but low manufacturing costs mean that solid discs are often used in the front brakes of light cars and also on the rear brakes of four-wheel drive vehicles, where the braking loads are relatively small. All discs, including ventilated discs, need to be strong against frictional heat and good at dispersing heat, which is why the majority are made from cast iron.



▶ Ventilated Discs

Two discs are layered together and there are holes between them to provide ventilation. These were initially developed for racing cars but are also now common in passenger cars. Compared to solid discs, the surface temperature is reduced by around 30%, increasing resistance to fade and lengthening brake pad life. The downside is that their double thickness makes them a little heavier.



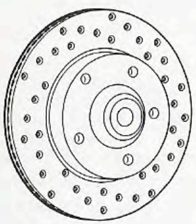
Advanced Ventilated Disc Types

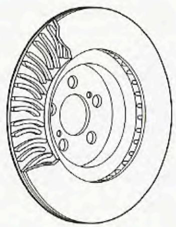
▶ Cross Drilled Discs

Similar to a ventilated disc, but with additional holes drilled on the disc surface to increase heat dispersion and cooling. These are frequently used in racing cars and high performance sports cars. The holes are also effective at removing the dust created when braking. Another type of disc called a "slotted disc" has channels machined into its surface to achieve the same effect.

▶ Spiral Fin Discs

Two discs are layered together, with heat-dissipating fins arranged in a spiral shape between them. These fins are designed using numerical analysis of the airflow in the disc, to provide maximum air flow through the disc. As a result, heat is dispersed extremely efficiently as the wheels turn. These discs are used in high-performance sports cars and heavier high-powered saloons.



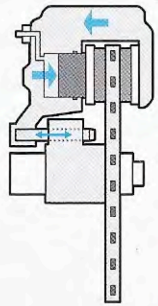


Discs and callipers

Types of Calliper

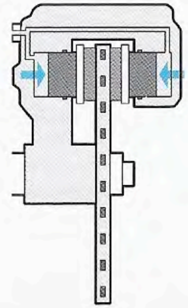
▶ Floating

A floating calliper has a piston mounted on one side, which pushes the brake pad against the disc when the brake pedal is pressed. The opposing force presses the brake pad on the other side against the disc's other side. Contact between the pads and the disc is constantly adjusted, and there is no time lag between the action of the two pads, ensuring an identical braking feel every time. The calliper itself is small and light and can still provide braking power, even if the disc warps from extreme heat. Although they begin to lose effectiveness in in sustained racing situations, they present no problems at all for regular driving.



▶ Opposing Piston

This is a setup in which brake pistons are located on both sides of the disc, to squeeze the brake pads against the disc from both sides. Because this setup makes the callipers larger and heavier, there's little choice but to make the calliper body out of aluminium to reduce weight, which in turn makes it difficult to maintain proper rigidity for the calliper unless it is properly designed. It is very effective in racing on a circuit, but to fully utilise their full potential the brake discs also need to be floating mount discs; otherwise with normal brake discs the heat will distort the disc, putting it at an angle so that the brake pads cannot properly engage the disc surface. With larger brakes becoming popular, multiple piston brakes with 4 pot and 6 pot callipers having a wider brake pad surface area have also been applied to commercial cars as well. A visibly large, opposed piston calliper peeking out from behind the alloy wheels is a strong indication of the car's high performance.



Suspension

CHAPTER 02
Mechanism

Dampers for Controlling Body Movement

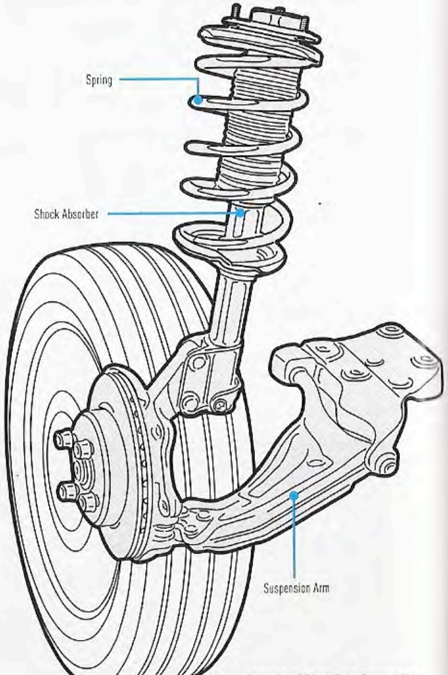
Compression and extension may seem like a simple process, but without a proper suspension system you wont be able to drive a car straight, let alone control one.

Construction and Principles

The suspension is the mechanism positioned between the body and the wheels to absorb the shocks that the wheels receive as they support the body of the car. It also has an important influence on handling, and as such, is an important mechanism in a car's construction. Suspension can generally be categorised into dependant suspension systems where the movement of one wheel affects the wheel on the opposite side, or independent suspension where left and right side wheels move independently without affecting each other. Examples of dependant suspension include beam or live axle, linked or torsion beam suspension and independent suspension, including those such as strut type and double wishbone suspension.

The suspension itself is made up of springs, shock absorbers and linkages. The springs absorb the shock from the road surface, and the dampers suppress the vibration of the springs to provide ride comfort and stability. The links restrict the movement of the tyres, so that the tyres will maintain optimal contact with the road surface. The suspension system plays an important role in pushing the tyres against the road surface through the springs, and thereby regulating their positioning.

The illustration shows a strut-type suspension. After it was first used in Japan in the Toyota Corolla, it went on to become an extremely common suspension type in production cars. In a strut type suspension the casing of the strut damper acts as and replaces the upper arm of a double wishbone suspension. This reduces the number of necessary components and allows for a larger engine bay.

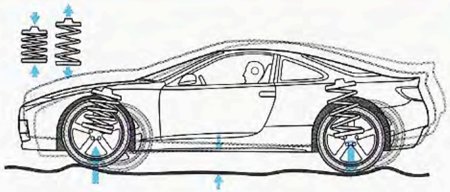


Example of Strut-Type Suspension

Controlling driving, turning and stopping

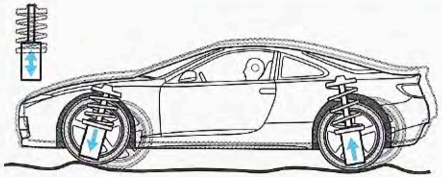
▶ Springs

Springs absorb the impact taken by the car during driving and, as well as lessening the shock, ensure that the car stays at a constant height. In addition to ensuring control, the springs are also an important factor in handling and stability. It is no exaggeration to say that the setting of the springs alone can greatly affect a car's performance. Metal coils are most commonly used, but some cars also have air-powered pneumatic suspension.



▶ Shock Absorbers

A coiled spring can absorb impact when weight acts on it, but once it has done so, it will not stop bouncing vertically. The shock absorbers are what dampens its movement (also called dampers). The most common type of shock absorber uses resistance created by a piston moving through oil and gas. The slower back-and-forth movement serves to absorb the violent vertical movement of the spring. Shock absorbers affect control and stability in the same way as springs do.



▶ Suspension Arms

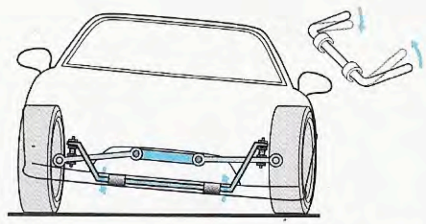
The suspension arms are the parts that control wheel movement. They are attached to the body and axle with bushings in between. There are various types, such as the A-arm and I-arm. They are usually made from pressed steel, but some sports models use aluminium components to reduce weight. In the case of suspension arms that are in sets of two as in a double-wishbone suspension, the top arm is called an upper arm and the bottom arm is called a lower arm.

▶ Suspension Bushings

Suspension bushings are shock absorbing materials placed at the joints of metal links and arms of the suspension or other mounting locations on the body. If the bushings are too soft, they will deform under large loads such as may occur during cornering. This will create an unwanted movement of the suspension and be detrimental to control and stability of the car. For this reason the suspension bushings are normally made of rubber material with very good shock absorption characteristics, but on competition racing cars, spherical metal joints called pillow balls are often used instead, so that the suspension will move with the highest precision possible. The suspension bushings are very important components that ensure the proper performance of the springs and the shock absorbers.

▶ Sway bars/Stabilisers

A sway bar or stabiliser is a stabilising device that helps to suppress roll in vehicles using a torsion bar spring. It is also sometimes called an anti-roll bar. It is connected to both ends of the lower suspension arms and only reacts to uneven movement of the left and right suspension. For example, when cornering, the body of the car on the outer side of the turn will sink down, while the body on the inner side of the turn will be lifted up. The sway bar will work to equalise this motion of the left and right sides, so that the car will not roll as much, stabilising the stance of the car. The effect of sway bars can be used to set a car against understeer or oversteer.



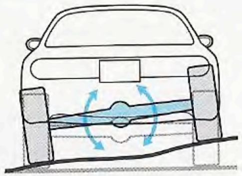
Types of Suspension

Although all suspension performs the same basic roles of maintaining vehicle height and absorbing the bumps and load changes of driving, each type has its own particular characteristic. The characteristics of the suspension will affect driving performance such as cornering, the control of a car (which also affects safety), and even things like ride comfort.

Suspension is always improving and new types are springing up all the time. A complicated system does not necessarily mean a better system, but the need to deal with bumps and undulations instantaneously and to keep the wheels in constant contact with the road surface has led to the introduction of ever more intricate solutions.

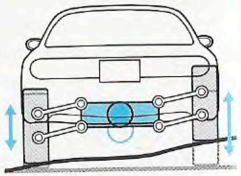
▶ Rigid Axle

In a rigid axle suspension, the left and right wheels are connected by a single axle. As a result, movement on one side also affects the other, making it easier to lose contact with the road. The axle beams and axle housing are heavy, increasing the unsprung mass of the car. However, as it is cheap to manufacture and also strong, rigid axle suspension is often used for the rear suspension of inexpensive rear-wheel drive cars.



▶ Independent Suspension

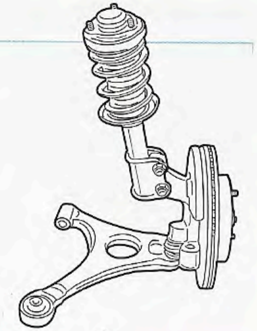
Independent suspension allows the left and right wheels to move up and down individually, making it excellent at dealing with undulations and bumps in the road. In the case of a rear-wheel drive car, this also helps transmit power efficiently to the left and right wheels. The system is light, stable and offers a comfortable ride.



Independent Suspension – The System of Choice for Most Sports Cars

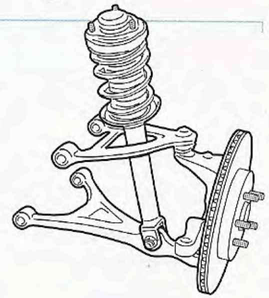
▶ MacPherson Strut

A simple suspension system consisting of a spring, shock absorber and lower control arm. The "strut" refers to the damper itself, which also serves as a support in this type of suspension. The upper part supports the body via a mounting rubber and the lower part of the shock absorber is supported by the lower arm. Fewer parts mean it is lightweight, and it has good stroke length, meaning that vibration can be absorbed over a broad range. The system was designed by Earle S. MacPherson, for whom it was named.



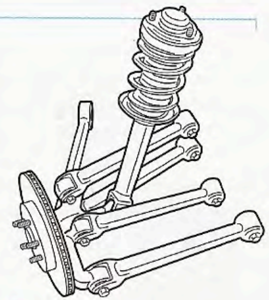
▶ Double Wishbone

A design that supports the wheels on an upper and lower arm joined together. The arms are usually in the shape of a V and resemble the wishbones of a bird. Depending on the shape of the arms and the car's layout, it can control changes in alignment and position of the car when accelerating relatively easily. It is also very rigid, making it a popular choice for sports cars that prioritise control and stability. However, it has a complicated construction using a lot of parts and takes up a lot of space.



▶ Multi-Link

This is an advanced form of the double wishbone system that uses between three and five arms to maintain the position of the axle rather than two. The arms are all separate, affording a lot of freedom as far as positioning is concerned and also allowing it to be set up very specifically. The increased number of arms allows it to deal with movement in many directions and keeps the wheels in close contact with the road surface at all times. This suspension type is often used for the rear suspension of high-performance FF cars to maintain stability at high speeds, and in high-output rear-wheel drive cars to maintain traction.



The characteristics of different suspension types

Wheel Alignment

Take a look at a piece of furniture with wheels attached to it. If you look straight down from above, you should notice that the axle of the wheel is at a slight angle in relation to the axle connecting it to the piece of furniture. This slight misalignment is what causes the wheel to move in a straight line when pushed, rather than wobbling.

Now imagine taking a car tyre and rolling it along the ground. If you stand the tyre up straight and roll it, it will move in a straight line, but if you lean it even slightly, it will turn in that direction as it rolls.

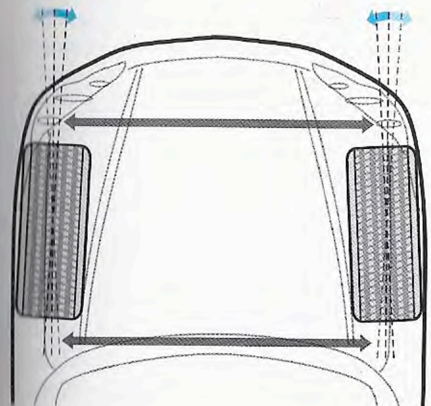
From this, we can see that when wheels are mounted on a car, if they are set to the right angle it will be possible to move the wheels in a way suited to the operational conditions of the car. This is the basis behind wheel alignment (or suspension geometry). Driving, turning and stopping all rely on the fact that the wheels are aligned properly. This "positioning" of the wheels can maximise the performance of the tyres and can set the characteristics of a car.

The page opposite illustrates the four basic angles of wheel alignment: the toe angle is the angle of the wheels when looking down from above, the caster angle is the angle of the suspension viewed from the side, the camber angle of the wheels when looking at them from the front and the kingpin angle is the angle of the suspension in relation to the wheel viewed from the front. These settings are adjusted in increments as small as 0.1 degrees/0.1 mm, so the margin for error is tiny and if a mistake is made, the car may not travel in a straight line or the handling may be adversely affected. You'll want to remember the different effects these settings can have.

Wheel angle affects road contact and handling

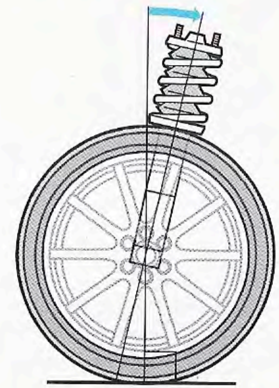
▶ Toe Angle

This is the angle of the right and left wheels when looking at the car from above. If the front of the wheels point outwards, this is called "toe out", and if they point inwards, it is "toe in". This angle has a large impact on the car's forward movement and if set at an excessive angle, will cause uneven wear on the tyres.



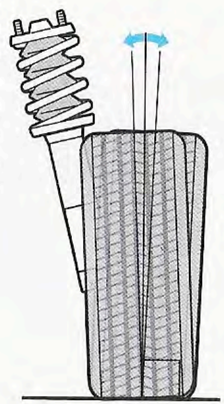
▶ Caster Angle

This is the angle of the front suspension relative to the front tyres when looked at from the side. The angle suppresses how much the wheel shakes from side to side, it also affects self-alignment torque (the force that tries to return the wheels to a straight position when the steering wheel is turned). If the caster angles of the right and left wheels are different, the car will pull in the direction of the shallower angle or the steering will pull to one side when braking.



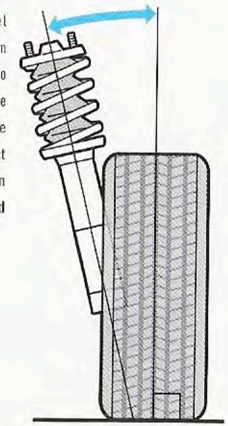
▶ Camber Angle

This is the angle of the wheels relative to the road when looking at the car straight-on. If the top of the wheels point inwards, this is a "negative camber". If they point outwards, the camber is positive. In most cars, the camber is set to be slightly positive to counteract the effects of heavy loads.



▶ Kingpin Angle

This is the angle of the wheel attachment axis when viewed from the front. Normally, it is adjusted to prevent changes in the road surface from pulling the wheel out of the driver's hand, but it can also affect forward driving, steering return (self-alignment torque) and steering force.



Tyres
CHAPTER 2
Mechanism

The Link Between Car and Road

Once it has passed through the drivetrain and the suspension, the power of the engine will finally be transferred to the road via the wheels. No matter how good the car, its performance will only ever be as good as its tyres.

High-Performance Tyres

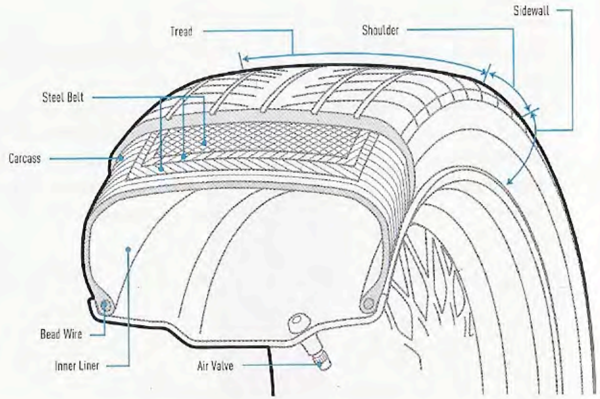
Tyre characteristics can be roughly divided into four categories: load support, shock absorption, acceleration and braking and maintaining heading in a straight line and during cornering. Once a good balance of these four basic functions has been established, the tyres are fine-tuned to suit specific needs.

Sports cars favour tyres that can accelerate, decelerate, and maintain heading well, to ensure good driving, cornering and braking performance. These tyres will be made from high-grip rubber that sticks to the road surface, and will be very rigid to prevent them from changing shape under load. This increases steering response when cornering, and allows corners to be taken at higher speeds.

Of course, high-grip tyres also have their disadvantages. Although they have a high capacity of grip when cornering, recovery when that capacity is exceeded is difficult, and a high level of driving skill is required. It will increase the amount of stress caused to the suspension and body, and roll during cornering is increased due to the extremely high grip. The tyres are so high performance that they can offset the balance of the car, and that means that the car itself has to be high performance enough to use those tyres in the first place. You should also remember that because there is a lot of friction between the tyre and the road, they wear out more quickly, which will detract from passenger comfort and increase noise.

Grip on wet roads is largely dictated by the pattern of grooves carved into the tyre surface. These grooves are designed to effectively rid the tyre of water picked up from the road surface, but also reduce rigidity, so striking the right balance is difficult, especially with sports tyres.

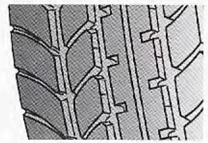
A car cannot exceed the limitations of its tyres and, for this reason, it is essential for a driver to fully understand tyre performance and characteristics in order to select a tyre that matches their needs.



Grip and rigidity – the key to speed.

▶ Tread Compound

This is the rubber used on the tyre surface that makes contact with the road. The soft rubber used for high-performance tyres keeps a strong grip on the road but wears out quickly, while for tyres on standard cars, where durability is a priority, a harder compound is used that will only maintain grip to a certain level. Tyres are normally hard and will not exhibit their full grip potential until they are heated to a certain level. If, however, they are overheated, their grip will be reduced.

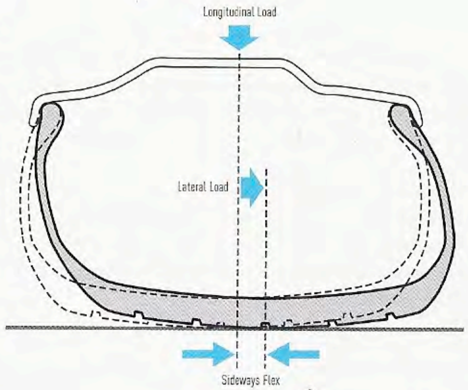


▶ Tread Pattern

The pattern of grooves carved into the part of the tyre surface that makes contact with the road. The main purpose of these grooves is to rid the tyre of water as the wheel turns, and many tyres will have a set direction of rotation for the tyre pattern that maximises the water shedding characteristic. On the other hand, as these patterns reduce surface rigidity, high performance tyres use a few large grooves rather than a complex pattern of small ones. There are also asymmetrical designs with fewer grooves on the outside edge to improve rigidity when cornering, but more grooves on the inside to rid the tyre of water.

▶ Casing Rigidity

The casing is the entire surface of the tyre, including the tread, sidewalls, bead etc. The forces acting on the tread from the road surface are transmitted to these various parts, until it reaches the base of the bead. It is important to have a rigid casing to avoid warpage in situations such as acceleration, deceleration and cornering, when the casing is under heavy load. However, as rigidity and driving performance is increased, passenger comfort decreases, so tyres are specifically tuned according to their characteristics and their application.



Wheels

CHAPTER 2
Mechanism

Aluminium Road Wheels

A 1kg reduction in unsprung weight is equivalent to a 15kg reduction in sprung weight. Lightweight road wheels help get the best performance when accelerating, decelerating, braking and cornering.

Unsprung Weight

Although often seen as a decorative item, aluminium wheels affect driving performance significantly. A car requires most power of all when accelerating from a standstill. It takes a lot of energy to make the wheels start to turn from a stationary position, and the heavier the wheels, the more energy is required. Lighter wheels require less energy and therefore less engine power.

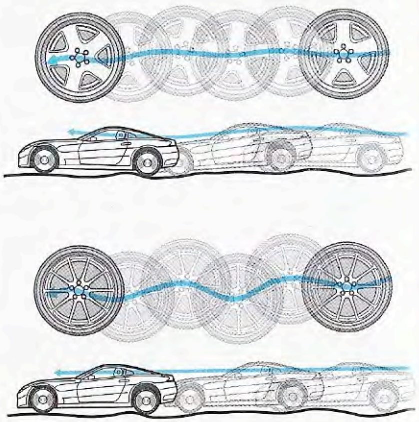
Weight not supported by the suspension is known as "unsprung weight", and has a significant impact on the drive performance of a car. If the wheels and tyres are light, acceleration and acceleration from a standstill are improved, while braking, and braking efficiency increase, as it becomes easier to stop the wheels turning. Suspension will also be smoother, improving passenger comfort and the movement of the car over the road surface. Improved fuel efficiency is another benefit.

The popularity of aluminium wheels in sports cars is testament to the performance advantages they offer. 1kg less of unsprung weight is equivalent to a 15kg reduction of sprung weight, and in the world of motor sports, unsprung weight is sometimes reduced further with the use of magnesium alloy wheels, which are even lighter than aluminium.

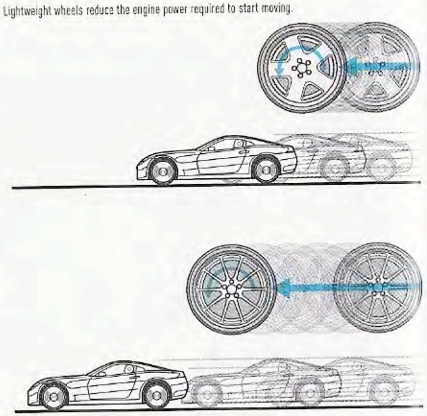
Mainstream aluminium wheels have the benefit of efficient heat conduction, and can effectively discharge the heat generated by the brakes. They are also more resistant to corrosion than steel wheels.

When changing to new wheels, you must be careful in your choice as increased size may cancel out the weight benefits of using a lighter material. A major increase in size of the wheel will have the inevitable effect of increasing unsprung weight, and the advantages of lower profile tyres need to be weighed carefully against the disadvantages of this increased weight.

The lighter the tyres, the better the contact with the road and the more comfortable the drive.



Lightweight wheels reduce the engine power required to start moving.



Types of Lightweight Wheel

▶ One-Piece

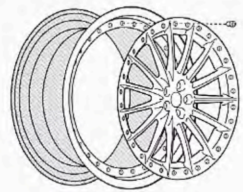
In this basic construction, the rim and disc are made from a single piece of metal. The wheels are machine-cut after casting (or forging), giving them a high degree of precision. There is relatively little freedom in design, but the fact that they are made from a single piece of metal makes them lighter and more balanced than 2- or 3-piece wheels.

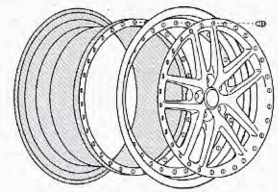
▶ Two-Piece

The disc and rim are made as two separate parts, which are then joined with nuts and bolts or welded together. The materials used to make the disc and rim can be different (aluminium, magnesium, titanium etc.), as can the manufacturing method (forging or casting). These wheels have the benefit of offering a wide choice in terms of disc design and the amount of offset.

▶ Three-Piece

The back and front of the rim are welded together, and the disc is attached with pierce bolts. The three-piece design has the same advantages as the two-piece design, although it is slightly heavier because of the pierce bolts. However, it has even more freedom in design than the two-piece, and wheels built for style are often of this type.





Manufacturing Methods

▶ Casting

A method whereby molten aluminum is poured into a mould. In two- and three-piece wheels, the high degree of design flexibility of the disc is an advantage. However, the metal needs to be quite thick for sufficient strength, which makes the weight advantage over steel wheels only slight. Despite this, its low cost makes casting the most common method in the manufacture of aluminium wheels.

▶ Forging

A block of metal is compressed with thousands of tons of pressure (to align the molecules of the metal), creating a resilient, hard material. Compared to moulding the metal is much stronger, so the thickness of the parts can be reduced and made to be very lightweight. The increased rigidity means that tensile strength is high, but it is weak against bending forces. It is also more expensive to produce and the design possibilities are limited because of the manufacturing process. Materials are not limited to aluminium, and there are cases where racing cars and some sports cars use magnesium forged wheels which are even lighter.

The many benefits of reduced weight

Aerodynamics
CHAPTER 2
Mechanism

Aerodynamics – The Effect of Air on the Body

Body design can completely transform high-speed performance, improving top speed, stability and efficiency. No discussion of car design would be complete without a look at the importance of aerodynamics.

Air Resistance and Lift

At high speed, the effect of air resistance is huge, at times making it feel as if an invisible wall of air is stopping the car from going any faster.

Once a car is travelling over 80km/h (50mph) the effect of air resistance cannot be ignored, as after that point, air resistance increases as a square of the car's speed. That is, if the car's speed doubles, the air resistance quadruples, and if its speed increases by three times, the air resistance increases by nine times. There is also the roll resistance of the wheels, but this resistance is not as critical because when the engine's power can no longer overcome the wall of air, that is the effective top speed of the car. In race cars and sports cars that need to achieve high speed and ensure performance in the high speed range, and even in road cars that need to achieve maximum efficiency, the reduction of air resistance is a major concern.

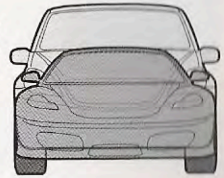
Cars lower to the ground have less air resistance than taller cars, and flowing shapes or wedge shapes that allow air to pass smoothly over them are also less resistant. Designs with flush body surfaces that have no protruding bumps or parts will also allow air to pass more freely.

On the other hand, it is important to bear in mind that the majority of low-resistance body shapes resemble aircraft wings when viewed from the side, and exactly like wings, air flows faster over them than beneath them, generating lift which causes the car to lose contact with the ground. Suppressing lift increases air resistance however, and an important part of design development is determining where to place the balance between air resistance and lift.

Furthermore, the disruption to straight line stability by crosswinds also needs to be taken into consideration, meaning that an aerodynamic body requires consideration for a total balance between air resistance, lift and yawing moment.

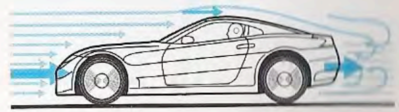
▶ Frontal Surface

The silhouette of the car's body when viewed from the front. The greater this area, the more air resistance will be encountered. The reduction of frontal surface area, or wind resistance, is one of the reasons that sports cars tend to have lower bodies. A large frontal area is a disadvantage of boxier cars and MPV's.



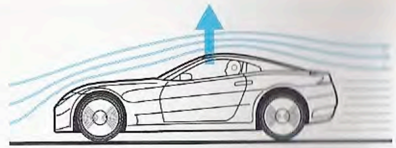
▶ Cd – Drag Coefficient

A number that represents how smoothly air passes over an object. This is a fixed value, and as such, is not affected by speed. Air resistance is calculated by multiplying the drag coefficient by the frontal area. Accordingly, if Cd is large, but frontal area is small as in many small sportscars, air resistance will still be small. The reverse can be said for saloons that have a larger frontal area.



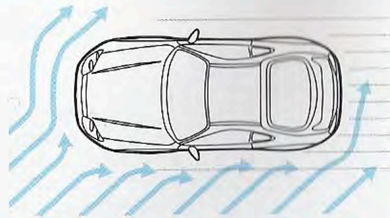
▶ Cl – Lift Coefficient

This is a number that represents the upward force on a car caused by air when travelling at speed. The opposite force is called "downforce" or "negative lift". Achieving downforce means increasing resistance, and ensuring stability is a matter of finding the balance of downforce in the front and rear.



▶ CYM – Constant Yawing Moment

When driving, winds do not always meet the car head-on. The force which occurs at the centre of the car, acting to spin a car hit by crosswind, is called the "Yawing Moment". Cars with a small CYM will be resistant to crosswinds, and in general, tall cars with a higher center of gravity are more affected.



Factors that inhibit high-speed performance

Spirit

Innovative Technology Vol. 3

Cars have always used cutting-edge technology, and constant advances in this technology have improved their performance whilst simult[illegible] making them more enjoyable to drive. Let's take a look at some of the technologies that have shaped the automobile, and the ways in wh[illegible] innovations have caused it to evolve.

INNOVATIVE TECHNOLOGY

Technologies that Have Transformed the Automobile

The automobile is a technological work of art. Today's cars are modern marvels, crammed with the latest innovations from such varied fields as mechanical engineering, material engineering, information technology and aerodynamics.
The field which has had perhaps the greatest impact on automobile development in recent years is electronics. Since the 1980s, cars have undergone dramatic changes thanks to advances in electronics technology. If you have a car manual to hand, why not have a flip through? You're likely to come across such terms as "ABS" (Anti-lock Braking System), "TCS" (Traction Control System) and "Satellite Navigation", all of which are recent electronics innovations that have changed the way we drive.

Modern cars extend electronic feelers out to the world around them and process the information gathered to assist with driving in all kinds of ways. For example, the ABS and TCS systems mentioned above are governed by speed sensors attached to the wheels.

These sensors constantly monitor the revolution speed of all four wheels. When the brakes are applied on a slippery road surface, causing the wheels to lock, the ABS function will instantly relieve the braking power applied to the wheels and restore their grip. Meanwhile, in the case of TCS, the wheel speed sensors detect wheelspin caused by the engine overpowering the tyres. When excessive throttle is applied and traction is lost, the TCS automatically suppresses engine power, again restoring lost grip. Wheel speed sensors are just one part of a vehicle-wide information network known as the CAN (Controller Area Network). In addition to wheel speed data, the CAN receives and processes all kinds of information, including steering angle, engine revs, coolant temperature, oil temperature and the amount of G-force acting on the car.

By assessing and processing this information in an integrated manner, modern cars have made safer, more controlled driving a reality. In the pages that follow, we'll be taking a look at the various technologies that make up the modern car and examining the areas of the vehicle that they affect.

Advances in electronics continue to occur at an incredible pace and could eventually lead to the establishment of networks that connect cars to one another, or even to entire transport infrastructures. The above illustration is a concept drawing of a Mercedes Benz connected to just such a network. If the car skids on a frozen surface, that information is transmitted to other cars driving in the vicinity to warn them of the danger. Below is an illustration of a Nissan GT-R, a car with electronic eyes mounted all over it to aid in advanced vehicle control.

ENGINE

In Pursuit of Efficiency

Technologies that Have Transformed the Engine

Without a doubt, it is the continual development of the engine over the last 100 years that has made the automobile what it is today. The chief role of the engine is to burn a mixture of fuel and air as efficiently as possible, and enhancements to improve this capability have driven the development of the engine since it was first invented.

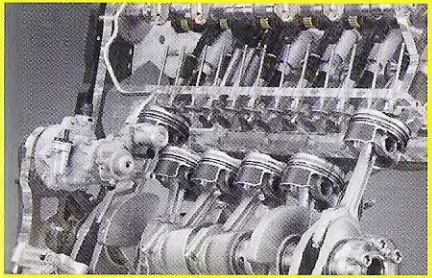
One such enhancement is the development of newer and better valve configurations, and in particular the appearance of the DOHC (double overhead camshaft). The first petrol engines used a side valve configuration where the intake/exhaust valves were located to the side of the piston, opening when pushed upwards. However, with this layout, not only is it impossible to increase compression to any great degree, there is also a poor flow of air-fuel mixture, making it unfeasible to increase the engine's rotational speed beyond a certain point. In order to remedy this, the OHV (Overhead Valve) was conceived, and a configuration called OHC (Overhead Camshaft) developed. A belt was used to connect the crankshaft to a set of gears on top of the engine, and a rod called the camshaft was connected to those gears to open and close the valves.

A DOHC (Double Overhead Camshaft) is an OHC camshaft that is split into two parts. These two camshafts operate the intake and exhaust valves separately, making higher revolution speeds possible, and allowing more powerful engines to be built. Although the DOHC itself was invented at the beginning of the 20th century, it was not until the 1980s that it saw widespread use in production cars (→p.82). The next major innovation was the variable valve system. Intake and exhaust valves let the air-fuel mixture in and out of an engine, but the timing and rate at which these valves open and close used to be fixed. Variable valve systems allow the timing and rate of valve opening and closing to be adjusted depending on various factors. In the 1980s, manufacturers such as Mitsubishi and Nissan took the variable valve system to the mass market. Amongst these, the VTEC system, introduced by Honda in 1989, had particular impact. VTEC switches between two cams – one for high-speed use and the other for low-speed use – when the engine hits a certain number RPM range.

It has received wide recognition as a system that improves both low-end torque and high-end power. Then, in 2001, BMW introduced Valvetronic. By making it possible to freely vary the amount of intake valve lift, this engine rendered the throttle valve unnecessary and achieved dramatic improvements in response, power and fuel consumption that inspired a whole series of similar systems.

Finally, let's look at the development of another technology that has been hugely important in the evolution of the engine – direct fuel-injection. Traditional engines add fuel to air before feeding it into the combustion chamber through the intake valve. Direct fuel injection, on the other hand, feeds only air into the intake valve, and then injects fuel directly into the combustion chamber itself. Doing so not only improves power and fuel efficiency, but also reduces harmful emissions such as nitrogen oxide.

Direct fuel-injection can be combined with both turbochargers and superchargers, and is found in the latest sports cars. This revolutionary technology is essential for petrol engines to survive the 21st Century.

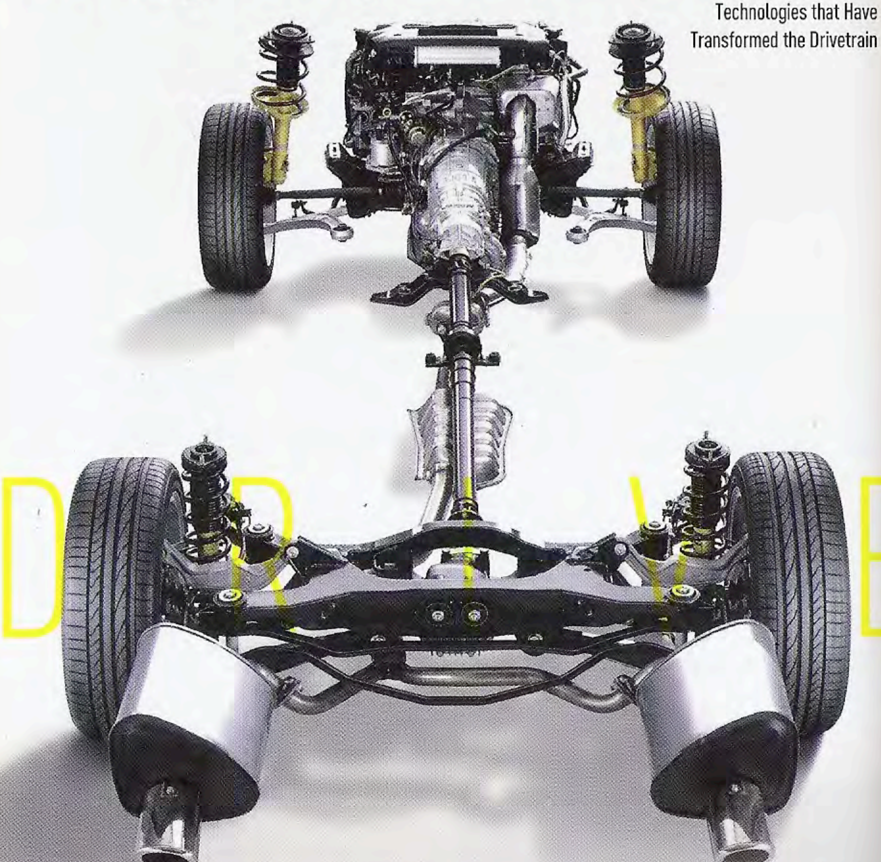


In Pursuit of Efficiency

Top-left is the Mercedes 300SL which, in 1954, became the first production car to feature direct fuel-injection. Bottom-left is a cutaway model of the Valvetronic six-cylinder engine introduced by BMW in 2001. A rocker arm and an intermediate arm slotted between the valve and camshaft continually adjust the lift of the intake valve. Above is Honda's VTEC engine (advanced VTEC, introduced in 2006).

Taking Charge of Transmission

Technologies that Have Transformed the Drivetrain



The drivetrain, also known as the powertrain, refers to the mechanism that transfers the power generated by the engine to the wheels. Perhaps the most important part of the drivetrain is the gearbox. Left unmediated, the rotation of the engine is too fast to turn the wheels. The gearbox uses gearing to bring this rotation down to usable speeds and the various gears can be shifted between as appropriate, as well as enabling movement in both forward and reverse.

As one might expect, early automobiles were only able to employ manual transmission (MT) for changing between gears. Unfortunately, since manual transmissions at that time did not have synchromesh mechanisms, they took some skill to operate. Automatic transmission (AT) was developed to make driving easier. The first ever automatic transmission, known as the "Hydramatic", was an optional extra for GM's 1940 model Oldsmobile.

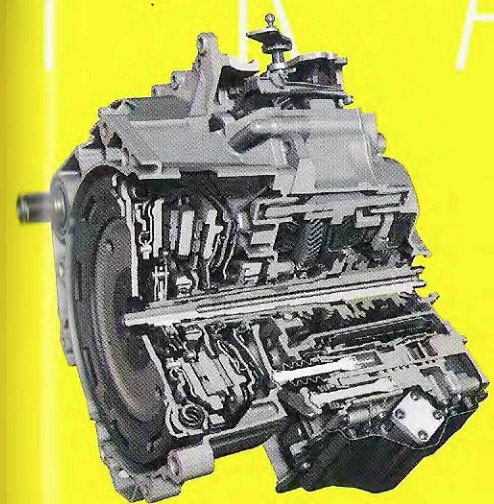
AT and MT have both come a long way since then, but as the 20th century drew to a close, a way to combine both was developed. In 1990, Porsche announced a manual-shift-enabled automatic transmission system known as "Tiptronic" for its 911 model. Following on from this, BMW launched the SMG, which featured an electronically operated clutch, and a move towards towards semi-automatic and two-pedal systems in sports cars began in earnest.

The DSG (Direct-Shift Gearbox), first fitted to the Audi TT in 2003, brought yet more innovation to this trend. This gearbox, which had its roots in 1980s Porsche Group C cars, completely separated the engaging and disengaging of the clutch and the gearchange operation, resulting in shift times surpassing those of cars with manual transmissions. Since these gearboxes also make convenient automatic drive possible, Volkswagen and Audi have increased the number of models with DSG fitted as standard and are continually working to improve the system.

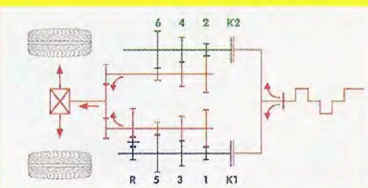
Another drivetrain innovation that cannot be overlooked is four-wheel drive (4WD). 4WD systems were originally developed for off-road driving, but with the appearance of the Audi Quattro in 1980, it became clear that the performance offered by four-wheel drive was just as valuable when driving on paved roads. Since then, thanks to the success of Japanese cars such as the Mitsubishi Lancer Evolution, Subaru Impreza and Nissan GT-R, its value has been recognised and many supercars these days employ 4WD layouts.

4WD, which distributes the power of the engine to all four wheels rather than just two, has always provided a high level of driving performance, but the latest 4WD cars have improved on this even further with the incorporation of various electronic devices. Mitsubishi's ACD/AYC, Honda's SH-AWD, and Nissan's ATTESA E-TS systems are all good examples. Not only do they manage the distribution of power to each of the four wheels, they also actively generate torque differential in the inside and outside wheels when cornering, resulting in improved cornering performance. Moreover, from a safety perspective, 4WD pairs well with ABS and traction control systems such as VDC and VSC, making it possible to ensure a higher level of safety.

DRIVETRAIN



The Evolution of Transmission: VW Group's DSG



Above is a schematic diagram of the DSG. The transmission houses two shafts – one blue, one green – which are responsible for odd and even gears respectively. For example, when driving in 3rd gear, the engine power is transferred to the wheels from clutch 1 (K1) via the odd gear shaft (blue). At this point, 4th gear is already connected to the even-numbered shaft and revolving. Shifting gears is simply a matter of disengaging clutch 1 (K1) and engaging clutch 2 (K2).

The Framework that Supports it All

Technologies that Have Transformed the Chassis

CHASSIS & BODY

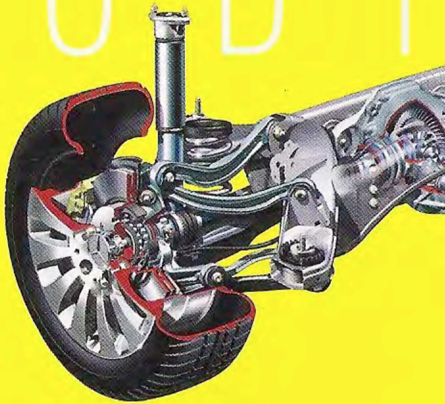
The chassis is the entire frame of an automobile, including its suspension. Since we've mentioned it, let's begin by focusing on the suspension. Suspension was first developed for horse-drawn carriages as a way to soften the impact of bumpy roads, and the technology was then transferred to automobiles. However, as cars improved over time, it became apparent that the build and quality of the suspension could have a dramatic impact on driving performance and, as a result, a whole range of suspension types have been developed for a whole range of vehicles and situations. The most important suspension innovation of all was perhaps the development of independent suspension. Early suspension modelled on that used in horse-drawn carriages was generally rigid axle suspension attached to the left and right wheels. This setup had positive points: it was simple to build, it was stable and the wheels rarely left the road when traversing bumpy terrain. However, its components were heavy and it struggled to keep both wheels on the road when cornering.

In order to overcome this, independent suspension was developed. There are numerous types of independent suspension, including strut, swing arm, wishbone, and multilink, but they all enable independent movement of the left and right wheels, providing greater flexibility and allowing the vehicle to adhere better to the road. The adoption of independent suspension led to improvements in driving performance, which greatly benefitted sports cars in particular (→p.102). The first production car to adopt four-wheel independent suspension was the 1931 Mercedes Benz 170. Due to the fact that it was a complicated mechanism to build, early adopters were predominately prestige cars and it was not until after the Second World War that independent suspension became common in production cars.

The next major innovations in chassis design were in the materials that make up the frame. For a long time, cars had been constructed from steel. However, as the 20th century progressed, cars gradually piled on the pounds as they were forced to contend with safety and environmental issues and, as a result, a major review of the materials that make up a car was undertaken. Firstly, the steel itself was strengthened by adding carbon and silicon.

High-tensile steel sheet metal became increasingly prevalent, enabling parts to become progressively more lightweight, and recent years have seen the introduction of even stronger super high-tensile sheet metal. Meanwhile, in the field of sports cars, aluminium was starting to enter into use. In 1989, the Honda NSX took the motoring world by storm, becoming the first mass-produced sports car to feature an all-aluminium monocoque body. Subsequently, Audi developed the ASF (Audi Space Frame), an all-aluminium monocoque implemented into the A8 and R8, and in 2003 Jaguar succeeded in delivering an aluminium monocoque with the third generation XJ.

Carbon fibre has an unparalleled advantage when it comes to lightness. CFRP, which combines carbon fibre and plastic, boasts supreme resistance to abrasion and heat. It is unlikely to become widespread in production cars due to its being so costly and difficult to recycle, but it is fair to say to say that in the world of super cars, it is fast becoming the material of choice.



Multi-Link Suspension

Multi-link suspension represents the latest in suspension technology. Numerous independent arms (links) enable precise control over wheel movement up, down, forward and aft, but this benefit comes at a high price and is currently used only on expensive cars.

ALL LINKS CLICKABLE

CHAPTER

03

Apex [The Gran Turismo® Exclusive Magazine]

Tuning & Settings

Setting Up Your Car

Engine
CHAPTER 03
Tuning & Settings

Improving Engine Performance

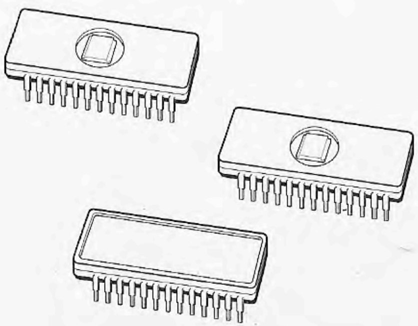
Tuning an engine for maximum power alone will result in a car that is hard to handle and which won't perform well on the track. Tuning is a matter of trying to achieve the optimum settings for your vehicle based on the individual track and your particular racing style.

Fine-Tuning

Replacing the Engine Control Unit (ECU) and improving the efficiency of the exhaust sytem are some of the first basic steps in improving an engine's performance. Once these first steps have been taken, they set the base for making more serious modifications such as mechanical tuning or fitting a turbocharger. These first steps may not achieve a huge increase in power, but they will lead to smoother revs and quicker response. The stress added to the engine through these modifications is fairly small - and in fact this will actually protect the engine when placed under high load.

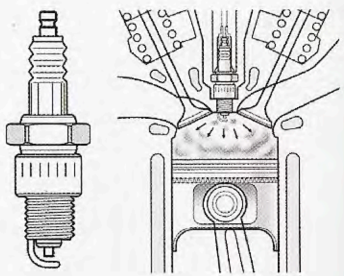
Engine Control Unit (ECU)

Updating the engine-control data saved on the ECU's ROM is known as "chip tuning". In addition to ignition timing, the fuel-air ratio, fuel injection volume and valve timing can also be calibrated. Chip tuning is necessary whenever you raise the turbo pressure, replace any intake or exhaust system parts, or make any modifications to the engine itself.



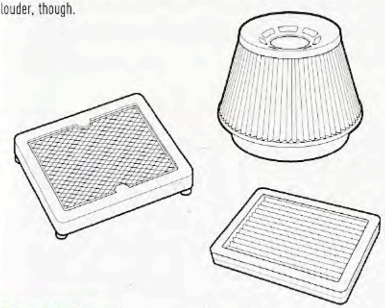
Spark Plugs

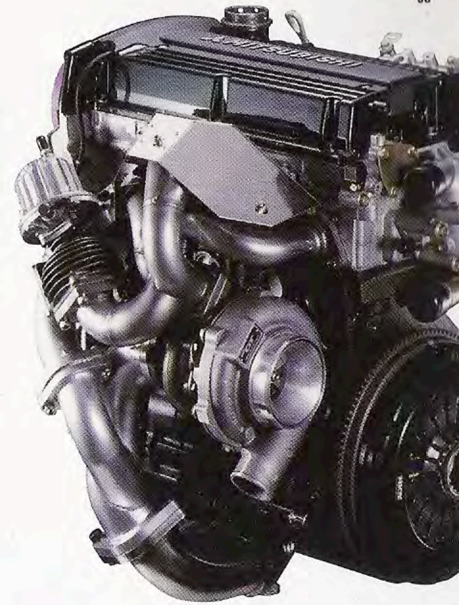
A strong spark is essential in order for the mixture of fuel and air in the combustion chamber to ignite properly. Even on a standard, unmodified engine, if it is run under high load continuously with regular spark plugs, the plugs will be strained with too much heat. This makes it especially important to upgrade your spark plugs when your engine has been tuned to produce more power. The increase in the engine's combustion will raise the temperature in the combustion chamber, making it more prone to pre-ignition. To avoid this, a more heat-resistant spark plug with a higher heat range must be used.



Air Filter

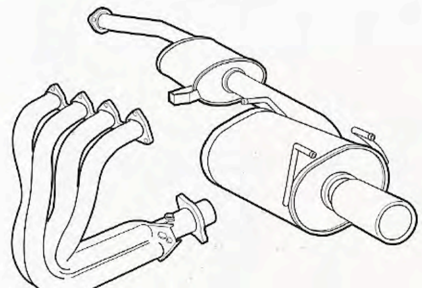
The standard air filter used to avoid dust and other impurities being drawn into the engine has a high level of resistance, and is inferior in terms of power output. It is therefore preferable to switch to a low-resistance air filter specifically designed for racing. Rather than boosting engine power, this has more to do with improving pick-up during acceleration and improving responsiveness at high RPM. Don't be surprised when the sound of the engine drawing in air gets louder, though.





Exhaust System

By reducing exhaust resistance, the engine will rev up faster and the accelerator response will become markedly sharper. Turbocharged engines in particular, which make use of exhaust energy, can see power increases of 10-20% just from an exhaust upgrade. However, be aware that changing exhaust components will affect the engine's torque characteristics, so it's always important to have a clear image in your mind of what effect you are trying to achieve.



Engine Oil

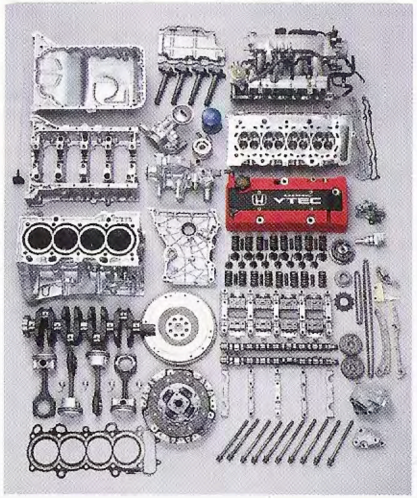
High-output engines put immense strain on their components, particularly their internal parts, so high-performance engine oil is absolutely essential. Engine oil functions as a lubricant, a cooling agent and a barrier maintaining an airtight state. If the oil is not able to coat surfaces properly, the cylinder will not be able to maintain pressure and the engine will lose power. The loss of lubrication between fast-moving metal parts can also result in those parts seizing or melting together. In addition, oil viscosity is an important factor which can increase friction loss (power lost through excessive friction), so chemically synthesised low-viscosity oils that maintain performance even under harsh operating conditions are now widely used.

The basics of tuning

Overhauling the Engine

Mass-produced engines cannot be said to boast perfect precision in their assembly, and there are cases in which they are not performing to their full potential. Completely disassembling the engine down to its smallest components and rebuilding it from the ground up with absolute precision can raise overall engine performance. While overhauling the engine in this way, you can boost its capabilities even further by replacing certain parts with more lightweight alternatives and balancing various parts at the same time for added effect. If you're not restricted by limits on engine displacement, you can even use this opportunity to increase the engine's displacement capacity, improving output and torque even further without stress.

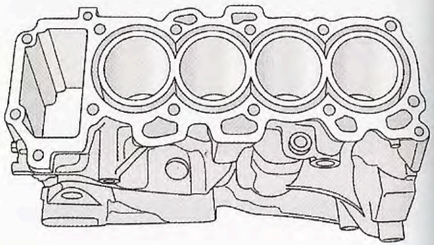
Some modern engines are often so finely balanced when they roll off the production line that they don't leave a great deal of opportunity for improvement through overhauling.



Increasing Displacement

This is the most effective way of improving performance when modifying the engine itself. By increasing the amount of fuel/air mixture burned, the engine output can be improved. This can be achieved by "boring up" the cylinder, making the cylinder bore larger and installing larger diameter pistons, or "stroking up", making piston stroke longer by replacing the crankshaft and connecting rods. Although both have the effect of increasing engine displacement, they each have different characteristics. Boring up is more suited for increasing engine RPM to give higher output, while stroking up increases torque at low and medium revs. However, as modern engines have become more lightweight, cylinder blocks have become thinner, making boring up to any great extent increasingly difficult.

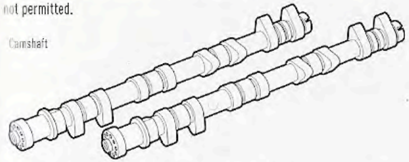
Cylinder block



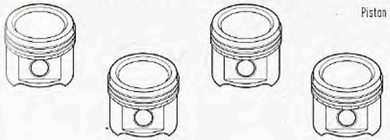
Balancing

In a normal engine, the weights of the pistons and connecting rods in each cylinder are all very slightly different. Also, if there is any deviation in the rotational balance of the crankshaft, this can cause resistance, which is a major cause of power loss. Balancing the engine involves disassembling the engine and carefully weighing each component. By making each part uniform in weight, and by correcting rotational balance to improve crankshaft movement, it can be made to run more smoothly and therefore more efficiently, to produce more power. In situations when modifying a part to correct the weight imbalance is not enough, the part is sometimes replaced altogether. This kind of tuning is absolutely essential for one-make racing, where major car modifications are not permitted.

Camshaft



Piston



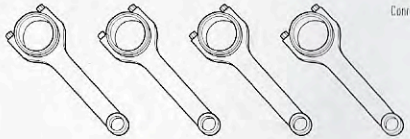
Reducing Weight

Engine parts that move at high speed are acted upon by inertia, causing frictional loss and reducing power. This can be alleviated by removing material from parts to make them lighter. This is normally performed together with balancing, but if the parts are grinded down too thin, it can cause problems with durability.

Reinforcement

When major tuning work is carried out on an engine, the strain put on each individual part is greatly increased, and there is a greater risk of parts being damaged. This makes stronger parts essential, but it is also essential for these parts to be lightweight. Reinforced parts that make use of new forging techniques, as well as new materials such as titanium alloys, combine a lightness that far surpasses regular engine parts for strength and durability. In racing and tuned engines, the use of aluminium forged pistons and titanium alloy connecting rods has become standard practice.

Conrod



Unleashing your car's full potential

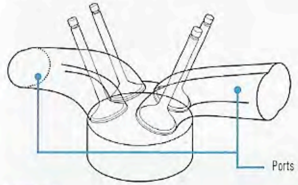
Increasing RPM

Engine output is a combination of torque and engine revolutions (power = torque x RPM). This means that boosting your engine's ability to reach high RPM will increase its potential output. The tuning needed to enable this centres on the cylinder heads, and the key to success lies in increasing the efficiency of air intake and exhaust at high revs. The standard way to achieve this is to replace the regular cam with a high-lift camshaft (→p.129). Although this means that the components around the valves need to be reinforced, it achieves the same effect as increasing the size of the intake and exhaust ports, improving power at high revs considerably. Incidentally, the engines most suited for high RPM are short-stroke engines, as their airflow efficiency is high but their piston speed is not as fast as that of long-stroke engines.

You can increase your engine's ability to reach high RPM and produce high output in a single stroke by switching to a high-lift camshaft. However, this will greatly reduce torque at low and medium revs and some pure racing engines are not even able to idle smoothly.

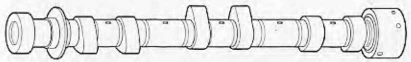
Ports

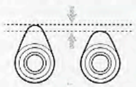
The intake and exhaust ports allow the fuel/air mixture to enter the engine and provide an exit for waste gases after combustion. Ideally, the flow through the ports should be as smooth as possible, but due to issues of cost this is usually not the case for the average engine. Rough surfaces characteristic of cast metals, the size of the passageways, distortion, etc. are all causes of intake/exhaust resistance. By polishing these surfaces to a mirror-like finish, a smoother flow of air can be achieved. Even by polishing the port alone, the feel of the engine will improve in the high RPM range, but you are unlikely to feel its full benefit unless you combine it with a complete tuning of the cylinder head, including polishing the head and replacing the cams.



Camshaft

The camshaft is the shaft that opens and closes the intake and exhaust valves. A high-lift camshaft is one that has higher raised sections along its length, which cause the valves to open for longer. Effectively, this provides the same benefit as increasing the size of the ports, and while it reduces torque at low and medium revs, it increases engine power dramatically at higher revs. While the sudden surge of power at high RPM undoubtedly makes the car harder to control, it is a technique often used when trying to get extra power from a naturally aspirated engine.





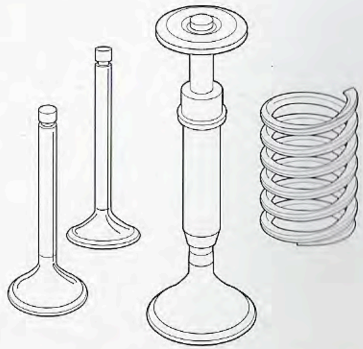
A normal cam on the right, vs a high-lift cam on the left. The higher raised sections cause the valves to open for longer.

Valves

At the same time as polishing the ports and replacing the cams, it is also important to consider increasing the size of your valves. This is a tuning method that enlarges the opening of the intake valve to allow more induction and to improve intake efficiency. Because bigger valves weigh more and are affected by more inertia, they are often made from ultra lightweight titanium.

Valve Springs

High engine revs can cause the springs that hold the valves closed to vibrate, leading to 'surging', where the expansion and contraction of the springs cannot keep pace with the movement of the camshaft. In an engine that has been tuned for increased power, a valve spring upgrade is important in order to avoid this. The need becomes even greater when a high-lift cam is fitted, as normal springs may not be able to cope with the valve's increased lift and, in extreme cases, the spring can stick to the cam and cause it to lock, or the valve and piston can collide with each other. Bear in mind, though, that fitting strong springs increases resistance and causes more wear to the area around the valves.



Increasing RPM to improve power

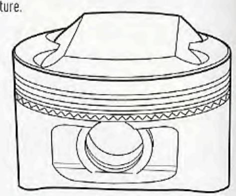
Increasing Compression

The greater the degree to which an engine can compress the air/fuel mixture, the more powerful the combustion that will take place when the fuel is ignited and the greater the power and torque that will be generated. The main part of this tuning involves the redesign of the combustion chamber capacity in the cylinder head. However if the compression is raised too high, this increases resistance when the engine is turning (compressing), and can also lead to abnormal combustion. High-compression engines require various adjustments to combat these problems, such as adjusting the amount of fuel entering the cylinder, switching to "cold" spark plugs and delaying ignition, and reinforcing the pistons and connecting rods to cope with the increased combustion power of the engine.

Increasing compression should ideally be performed in tandem with the increase of the engine's potential RPM. Also, as combustion will involve more force, the interior of the engine needs to be reinforced.

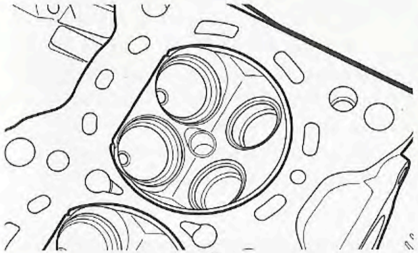
Pistons

The most common way to raise the compression ratio of the engine is to switch to high-compression pistons. As you can see from the raised upper part of these pistons, the combustion chamber is actually smaller than when using a regular piston, resulting in an increase in the compression ratio. However, increased compression leads to a hotter fuel/air mixture, and higher temperatures during combustion, making it more likely for "knocking" (incorrect combustion of the fuel/air mixture) to occur. This makes it necessary to take measures such as improving the flow of air/fuel mixture.



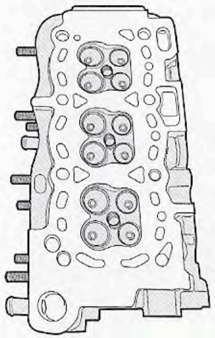
Combustion Chamber

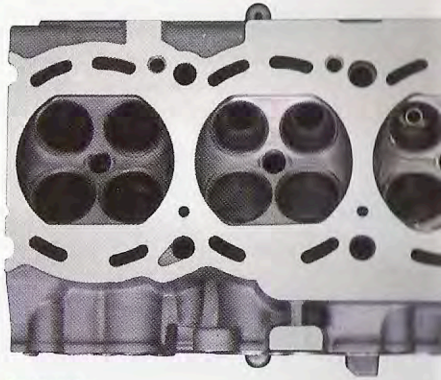
There are various combustion chamber modification techniques, one of the major ones being the "pentroof" type, which is superior in airflow and ignition efficiency, but the most common method for preventing knocking from high compression involves the use of "squish" or "quench" zones. These are areas cut into the combustion chamber where compression is concentrated, thereby serving to slightly reduce the overall compression ratio. However, creating squish areas can create discrepancies in the volumes of individual combustion chambers, so it's necessary to perform a precise measurement of the combustion chamber afterwards to make sure they are balanced.



Cylinder Head

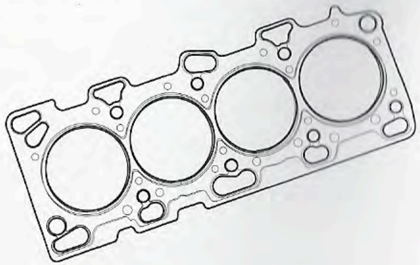
The underside of the cylinder head can be ground away in 0.1mm increments to gradually reduce the capacity of the combustion chamber, thereby increasing the compression ratio. This can also be carried out to correct any warping that may have occurred when running at extremely high temperatures, restoring the fit between the cylinder block and head and remedying any issues of compression loss.





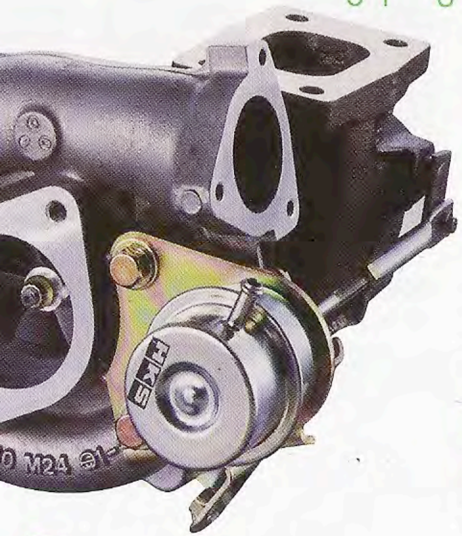
Head Gasket

The head gasket is the plate that sits between cylinder block and head, ensuring a good seal between the two, and preventing compression loss. Reducing the thickness of the head gasket has the same effect as grinding down the cylinder head, in that it serves to reduce the capacity of the combustion chamber, thereby raising the compression ratio. Head gaskets are now generally made from stainless steel, as it has high strength and boasts high levels of thermal conductivity. This allows compression levels to be optimised and avoids pressure loss from the cylinders.



Increasing combustion power

Delivering large quantities of compressed air



Forced Induction Devices

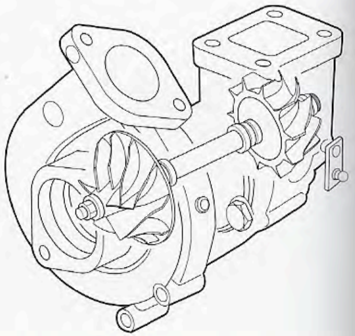
Increasing boost pressure or increasing the size of the forced induction device is a relatively easy way to achieve the same effect as increasing engine displacement without having to modify the engine itself. If you choose to combine this with mechanical tuning, you can achieve even better results. However it's important to remember that forced induction increases stress to the engine much more than naturally aspirated engines, and measures must be taken to account for this. In a naturally aspirated engine, a high compression ratio is the key to powering up the engine, but in an engine that is supercharged or turbocharged, compression actually needs to be lowered in order to prevent abnormal fuel combustion or damage to parts caused by the increased combustion. A lag in response is also an issue for turbocharged engines, and measures need to be taken so that the responsiveness of the engine is not critically affected.

Boost Pressure

Boost pressure is a figure indicating the volume of air taken in by a turbocharger and the compression under which the air is placed. It is, and is expressed in units of kg/cm2, kPa or psi. The higher this figure, the more power is gained. However, the more air that is taken in, the more fuel is needed to mix with it, which means that the ECU must be configured to add more fuel and it may be necessary to change or add fuel injectors so that fuel can be delivered in larger quantities. It is also essential to reinforce the internals of the engine in order to cope with the stress caused by the increased combustion.

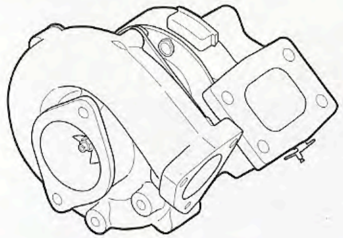
High-Flow Turbines

This is a turbo in which the size of the compressor wheel which compresses the air taken into the turbocharger is enlarged, greatly increasing airflow. A process known as "cutback" can be used to reduce inertia acting on the turbine wheel, thus allowing boost to be applied more quickly. This allows output to be increased with a minimum sacrifice of responsiveness.



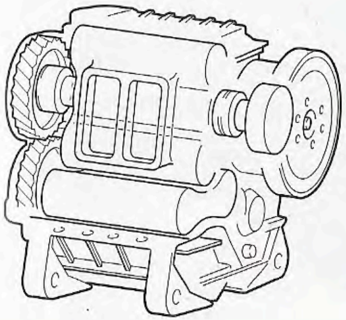
Increasing Turbine Size

This involves replacing the regular turbocharger with a larger one, since the size of the turbocharger is what determines the limits of a turbine's output. Although this delivers a marked increase in power, it has a disadvantage in that turning a larger turbine leads to a slower response of the engine. You need to be aware that unless you have a large displacement engine generating a large amount of exhaust and/or a powerful enough engine, torque at low revs will be very low and the turbocharger will only be effective at very high RPM, making the car extremely difficult to control.



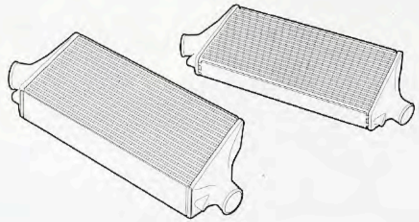
Supercharger

The principle behind the supercharger is similar to that of the turbocharger: essentially, it forces compressed air into the engine, giving it a boost in power. As with turbochargers, they can be bolted on to naturally aspirated engines, making them a relatively easy way to increase output. Because a supercharger does not cause a lag in accelerator response like turbochargers they are particularly useful on technical race tracks that require quick response.



Intercooler

The intercooler plays an important role in a turbocharged engine, serving to cool the air heated up by the compression of the turbocharger and improving the engine's volumetric efficiency. Intercoolers are fitted standard even in many production vehicles, but increasing their size boosts their effectiveness and enhances their cooling capability. However, compressed air takes too long to travel through an intercooler that is too large and starts to lose pressure. This can cause up to a 10-20% loss of boost pressure in some cases.



Rotary Engines

One of the main aims when tuning a rotary engine is to increase air intake efficiency. This is achieved by enlarging the intake ports, thereby delivering more air/fuel mixture to the combustion chamber. This effect is similar to that gained by fitting a high-lift camshaft to a reciprocating engine, but the nature of the power increase gained by relocating and enlarging ports can be very different. For example, peripheral porting, a technique used in competitive rotary-engine cars, causes an extreme loss of torque at low revs, and makes normal driving extremely difficult. Also on a rotary engine, the exhaust ports and turbocharger are very close together, allowing the exhaust gases to turn the turbine very efficiently. Combining both port and turbo tuning, the potential of this engine can be improved effectively.

One of the greatest advantages of tuning a rotary engine is its good compatibility with turbochargers, and turbo tuning can be combined to give excellent power and ease of operation.

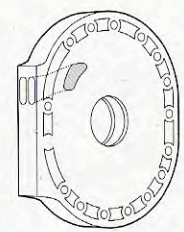
Porting - the key to improved rotary power

Balancing

Compared to a reciprocating engine, a rotary engine's structure is simple and it has fewer components. A lot of extra potential can be unleashed simply by improving the precision of each of these parts and carefully reassembling the engine. The most important part of this process is the setting of the seals. The rotor's corner seals correspond to the piston rings on a reciprocating engine, and if they can be arranged so that they all have exactly the same clearance, the rotor will turn incredibly smoothly, while maintaining the perfect amount of compression. If seals are set poorly, this can lead to loss of power and, in the worst cases, engine seizure.

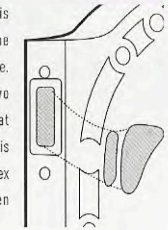
Side Porting

By widening the diameter of the intake ports positioned on the engine's side housing, air can be inducted into the engine at a faster timing than usual, increasing the total volume taken in and giving enhanced power. This offers similar benefits to fitting a reciprocating engine with a high-lift camshaft.



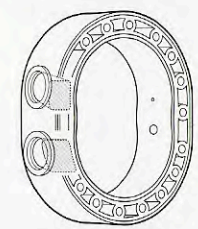
Bridge Porting

This is one method of tuning the side port. It is called a bridge port because the shape of the enlarged port has a 'bridged' section in the middle. The reason for having a bridge between two openings rather than one large opening is that when the port is enlarged to the very limits, it is necessary to leave this bridge to support the apex seal so that it does not warp or fall out when traveling over this section.



Peripheral Porting

This is a method of tuning a rotary engine by using a special adhesive to fill in the intake ports located in the side housing and then relocating them to the upper part of the rotor housing. The advantage of this is that the air/fuel mixture is delivered directly to the rotor housing, significantly boosting engine power at higher revs. Unfortunately, it also means that the engine will be unable to maintain torque at low revs due to the loss of the ability to differentiate between high and low speeds and adjust the air/fuel mixture accordingly. This means that the increase in high RPM performance comes at the price of a huge loss in low-end torque, and results in extreme power output characteristics that will be difficult to control.



Combination Porting

Also known as "cross-porting", this technique combines side porting (or bridge porting) with peripheral porting. It takes advantages of both types of porting by using a sequential system that uses the side ports at low revs and the peripheral ports at high revs.

Drivetrain
CHAPTER 03
Tuning & Settings

Tuning the Drivetrain

A vehicle's drivetrain translates engine power into speed. It needs to be as efficient as possible in transmitting that power to the road surface, and robust enough to handle high output with ease.

Getting the best performance from your engine

Final Gear Ratio

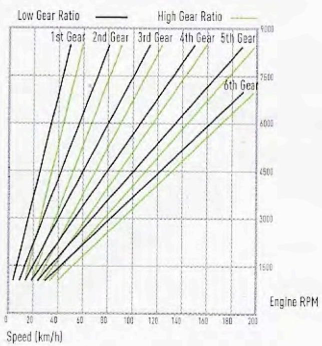
Altering the final gear ratio will allow you to choose between applying your engine power to top speed or acceleration. For example, in a high revving, high output engine with an extreme difference in characteristics from low to high RPM, you can make it easier to utilise its performance by setting the final ratio lower. This can then greatly improve the acceleration of the car.

High Gear Ratio

This is a good type of tuning if your aim is to increase the car's top speed, as it increases the speed from low revs. It also has significant advantages in terms of fuel consumption. The downside is that it takes longer to get the engine in its effective power/torque band, which makes acceleration sluggish. It can be difficult to achieve the desired power and torque when exiting tight corners, and will be more difficult to gain adequate acceleration.

Low Gear Ratio

With a low gear ratio, the engine can sustain high revs even in high gears like third and fourth. While top speed will be sacrificed, this makes it easier to draw out power and torque and will increase acceleration. You will be able to take full advantage of the engine's performance when accelerating out of corners, and these low gear ratios are particularly suited to technical courses with a lot of tight bends. The only downside is the tendency to over-rev due to the sharp increase in accelerator pedal response.



Transmission Gear Ratio

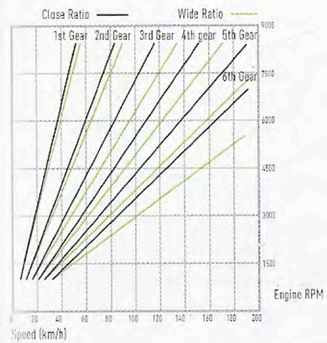
Transmission tuning generally refers to bringing the ratio of the gears of the transmission closer together (i.e. making their size more similar to create a "close ratio"). This makes it easier to stay within the powerband, and also greatly improves acceleration performance. However, depending on the final gear ratio, it can make the car more prone to over revving, and frequent gear changes will become necessary.

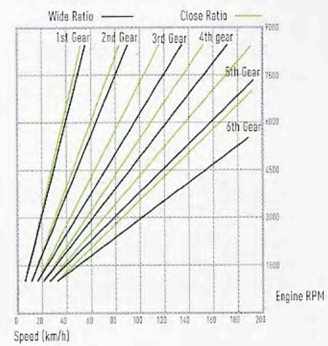
Close Ratio

A manual transmission with a close transmission ratio means that the difference in size between the gears is relatively small. The closer the ratio, the smaller the loss in RPM when shifting up through the gears and the more efficiently the engine's power can be used. This gearing is particularly suited to naturally aspirated engines whose powerbands have been narrowed by changing to a high-lift cam or other tuning tweaks. This is generally set up according to the course layout, combined with the matching with the final gear ratio.

Wide Ratio

Most production cars are set up with a priority on fuel efficiency, and therefore aim to keep engine RPM low. For this reason, the difference in size between their gears is relatively high. Unfortunately, this means that when you change gear, the engine power transferred to the ground is mild and acceleration is sacrificed. Normally, an engine will not be set up with a wide ratio between all the gears from 1 to 5 or 6, but will have a mixture of close and wide ratios to make the most of the engine's particular characteristics and deal with the layout of a track. For example, a close ratio may be used for the 1st and 2nd gears, as they are used for standing starts and accelerating, and then a wide ratio may be used for 3rd gear and above.

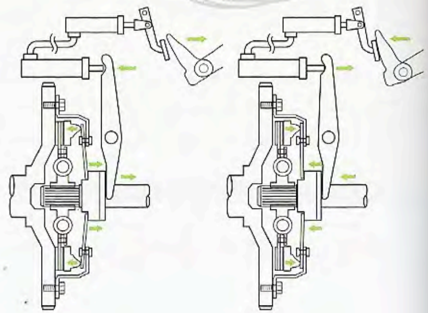




Limiting power loss and increasing responsiveness

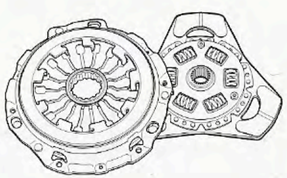
Clutch

Reinforcement of the clutch is essential in a highly-tuned vehicle so that the increased engine output can be delivered to the transmission with the minimum power loss, and gears can be changed effectively. Even the slightest amount of slippage will detract from acceleration performance. The idea is to increase the clutch disc's friction level and the clutch cover pressure in proportion with the increase in engine output and torque.



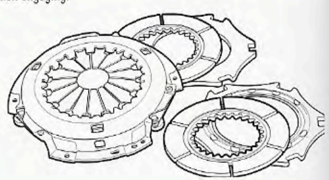
Disc & Cover

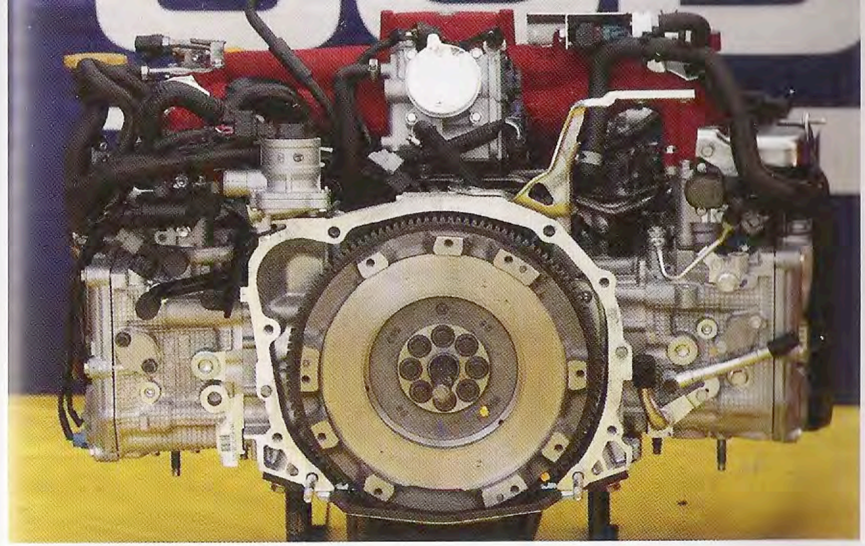
The most conventional method of reinforcing the clutch is to replace the existing clutch disc and cover with stronger parts. By increasing the friction of the clutch disc and the clutch cover pressure, the engine's power can be more reliably delivered to the transmission. These are vital components when enhancing engine power, and their advantage is that there is no delay in response even when they are aggressively used in sports driving. Metal clutch discs are now generally used because of their superior friction and resistance to wear.



Multi-Plate Clutches

Regular clutches only use a single clutch disc (also known as a "clutch plate"), but using a clutch with multiple plates serves to increase the area causing friction. Reinforced clutches, which boast a stronger clutch cover pressure and enhanced ability to transmit engine power, use between two and four plates. Friction increases in proportion to the number of clutch plates used, so the most suitable number of plates can be selected depending on the amount by which engine output has increased. While responsiveness and durability are increased, the downside of using multi-plate clutches is in their operation. They require more force to disengage, making the clutch pedal very heavy, while requiring more precision when engaging.



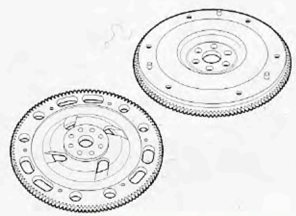


Flywheels and Propeller Shafts

Making the drivetrain more lightweight can be a highly effective way of improving acceleration response and acceleration. However, an extremely lightweight flywheel can make it difficult for the car to gain sufficient levels of torque when driving uphill, and additional tuning is required to compensate for this.

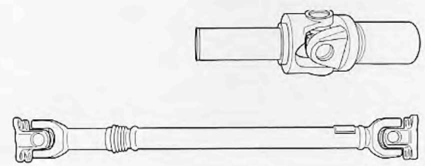
Lightweight Flywheels

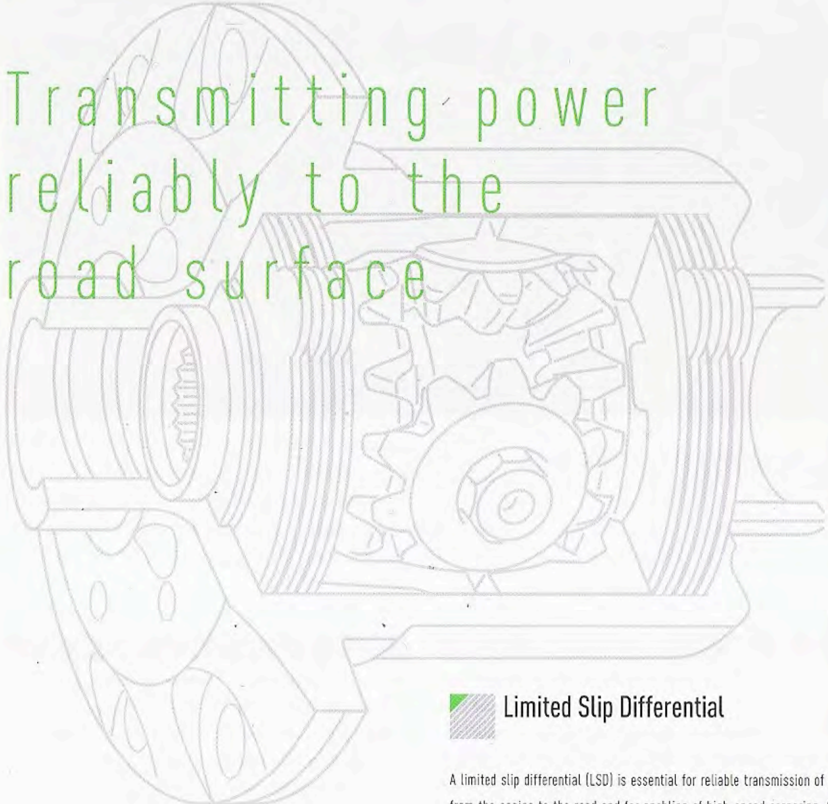
The flywheel is attached to the rear end of the crankshaft just before the clutch, and its main role is to prevent irregularity in the engine's rotation. The heavier the flywheel, the more smoothly the engine will turn. However, a heavy flywheel can be detrimental when speed is your objective, and it is preferable to replace the existing flywheel with a more lightweight one. Although this can make the engine rev less smoothly and reduces torque, it gives the advantage of improved response in acceleration.



Lightweight Propeller Shafts

A propeller shaft (also known as a drive shaft) transmits engine power from the gearbox to the differential. Replacing the regular propeller shaft with a more lightweight model can improve engine response and acceleration. Lightweight propeller shafts are generally made from carbon or fibreglass (FRP), and can be about half the weight of standard shafts. Reduced weight is of course the main benefit, but smoother rotation is another bonus of a lightweight shaft.



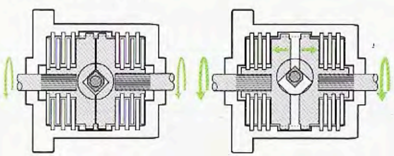


Transmitting power reliably to the road surface

Limited Slip Differential

A limited slip differential (LSD) is essential for reliable transmission of power from the engine to the road and for enabling of high-speed cornering. Of the several types of LSD available, the most effective at limiting the rotational difference in drive wheels is the mechanical type that makes use of a multi-plate clutch. This is because it allows the most freedom in setting the limit of rotational difference and can therefore be adjusted to give the best traction based on drivetrain layout, the peculiarities of a particular car, driving style or course layout and and a whole host of other factors. The downside to this freedom of choice is that the high load on the parts means that this type of LSD needs constant oil changes and periodic maintenance.

Mechanical LSDs allow the greatest freedom in setting the limit of rotational difference between wheels, but are specialised motorsports components and as such do not generally come fitted as standard.



Locking Factor

The locking factor describes the point at which a limited slip differential will limit the rotational difference between two wheels. In a normal (open) differential, the locking factor is 0% (ie, the wheels can rotate entirely independently of one another), whereas 100% represents total lock (ie, the wheels are forced to always rotate at the same speed). The higher the locking factor, the greater the limit placed on the amount of rotational difference allowed. A higher locking factor is not necessarily better. Rather, the locking factor needs to be carefully calibrated based on factors such as drivetrain layout, vehicle height and track width, and will change depending on the driving characteristics required. If the locking factor is set too high, understeer will be increased, leading to a loss of cornering ability. Generally speaking, a locking factor of around 50% gives the easiest control while still allowing the LSD to have an effect, but trial and error is the only way to find the perfect setting for a given situation.

Initial Torque

Initial torque refers to the amount of pressure acting on the discs inside the differential gear housing. Increasing or decreasing the initial torque will affect the amount of time it takes for the LSD to lock. The higher it is, the better acceleration response will be, as the LSD will lock almost instantly. The lower it is, the more gently the LSD will lock, and the easier it will be to drive. Usually, tuning an LSD will involve increasing the initial torque, but this can impair cornering ability, and in FF vehicles can worsen so-called "torque steering", so this is not always the case. Recently, LSDs with low initial torque settings and high locking factors have become more common.

Types of Mechanical LSD

▶ 1-Way

This type of LSD only works when the the car is accelerating. As it doesn't function without accelerator input, it allows the inside wheel to turn freely on the approach to a corner just as an open differential would, which makes for smoother cornering. This type of LSD is particularly well-suited to FF cars, as they are prone to understeer, but produces a marked difference in handling depending on whether the accelerator is applied or not.

▶ 2-way

This type of LSD functions whether the accelerator is pressed down or not. This produces fairly strong initial understeer, but allows the car to maintain stability when decelerating, making more extreme corner approaches possible. It also boasts excellent responsiveness and allows the driver to aggressively turn the heading of the car using the accelerator.

▶ 1.5-Way

This type of LSD combines the characteristics of both 1-way and 2-way systems. The LSD works as normal when accelerating, but its effect is reduced during deceleration in order to enable easier turning during the approach to a corner. It is an all-round solution without the quirks that affect the other types of LSD.

Body
CHAPTER 03
Tuning & Settings

Shaping Up the Body

Having a light, rigid body for acceleration and control is essential for motor-racing. No matter how much you power up your engine, if your car's body is too heavy and flexible, it's unlikely that the increased output will translate into real speed.

For precise handling

Weight Reduction & Rigidity

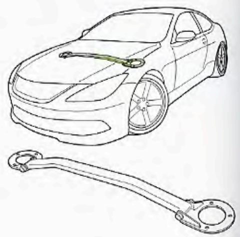
When aiming to increase your car's speed and agility, the reduction of weight and the reinforcement of the bodyshell is absolutely crucial. Reducing weight serves not only to increase acceleration, but also yields significant benefits when braking and cornering. Increasing rigidity is also essential for the suspension to move correctly when a large load stress is applied to the car, and to maintain firm contact of the tyres with the road. In order for a driver to understand the movements of a car in extreme driving conditions and to control the car precisely, a rigid body that will not deform is essential. On tracks such as the Nürburgring where the traction coefficient (μ) is low and strong G-forces are acting both laterally and vertically, it is impossible to achieve a single satisfactory lap in a car lacking sufficient body rigidity.

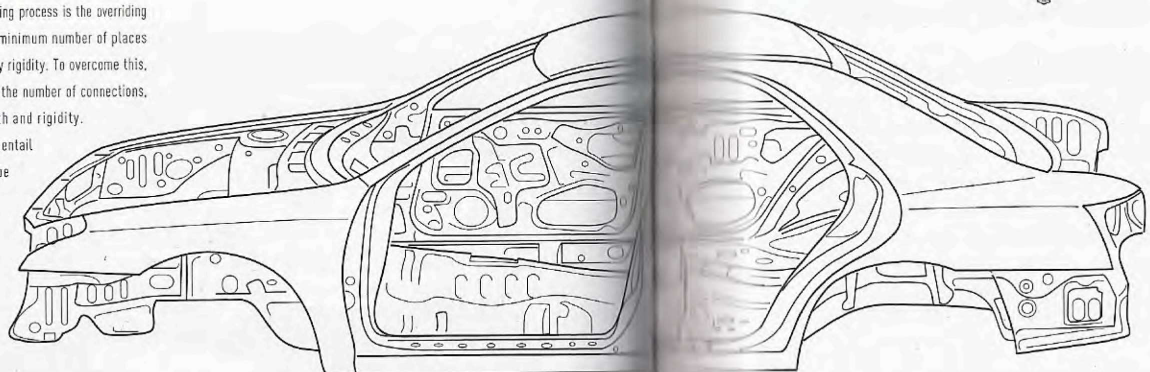
Spot-Welding

A car's body is constructed from metal panels that have been pressed together and then joined by welding them in spots at regular intervals. With mass-produced cars, where efficiency in the manufacturing process is the overriding priority, the panels are welded together in the minimum number of places necessary, which can lead to deficiencies in body rigidity. To overcome this, additional welding can be performed to increase the number of connections, to give a significant increase in body strength and rigidity. The advantage of this method is that it doesn't entail adding new components, so you don't have to be concerned about adding to the car's weight.

Strut Bar

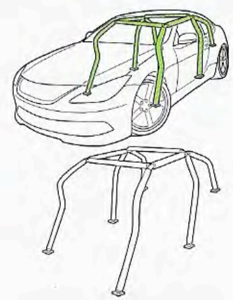
This is a bar fitted to connect the attachment points of the suspension (above the wheel housing) on the left and right sides of the body. It serves to enhance the rigidity of the front part of the body and ensures precise movement of the suspension, while also sharpening steering response. In general, a strut bar should be fitted in conjunction with upgrades to the springs, shock absorbers and bushings. It's common for strut bars to only be fitted at the front of the vehicle, but it's best to fit them on in the rear as well, for balanced rigidity.





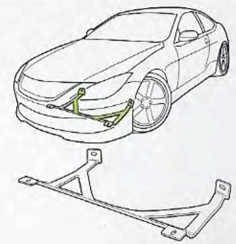
Roll Cage

Roll cages are designed to protect passengers during a crash, but they are also effective in increasing body rigidity. In order to achieve this, the there must be no space between the roll cage and the roof and pillar sections, and the roll cage must be firmly welded, rather than simply bolted on. The roll cage must also have plenty of struts and support points in order to actually provide a significant increase in rigidity.



Member Brace

A member brace is a metal bar that is highly resistant to bending and twisting. It enhances the rigidity of the floor of the vehicle, while at the same time serving to connect the suspension to the underbody, limiting any unwanted movement to maximise suspension performance. So, just as a strut bar supports the suspension and body inside the bonnet, a member brace supports the car from underneath the body. When used in conjunction with a strut bar the stability of the car's behaviour will improve even further.



Reducing Weight

The most effective way to improve a car's acceleration, braking and turning is to make the body more lightweight. Modifications can range from basic means such as removing the air conditioning system and any sound insulating materials, to replacing body panels with those made from lightweight materials such as aluminium or carbon fibre. Taken to the extreme, it can entail replacing the whole body shell with carbon fibre and the chassis with aluminium. However, always bear in mind that in order to maintain balance in the car's controls and handling, rigidity needs to be increased as well. In order to keep a low centre of gravity, it is more efficient and effective to start by focusing on reducing the weight from the upper parts of the car first.

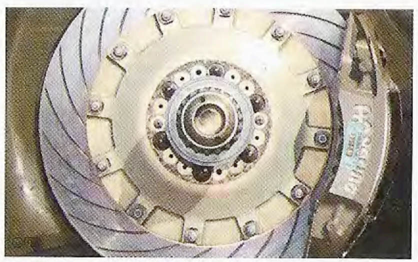
Brake
CHAPTER 03
Tuning & Settings

Improving Stopping Power

Improvements in engine output need to be coupled with an increase in braking power. The confidence to really put your foot down can only come from knowing that you are able to stop effectively. However, stronger brakes mean that more effective ways of dealing with excess heat also need to be employed.

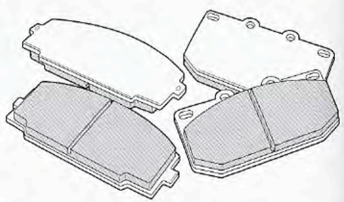
Boosting Brake Power and Avoiding Brake Fade

A tuned engine with a higher top speed requires a more powerful braking system that is stronger and more resistant against brake fade. At the most basic level, brakes can be improved by replacing the brake pads, and at the most extreme level, improvements can entail replacing the entire braking system with a high end system designed for motor racing. Just be sure to remember that the braking systems in racing cars are not necessarily ideally suited for all applications, making it important to select parts that are tailored to your specific needs. Also, bear in mind that larger brake pads or brake callipers will increase the unsprung weight of your car, which can have a negative effect on manoeuvrability. The golden rule is that brake power should always exceed engine power, but installing too effective a braking system in a lightweight car can cause an unbalance in its driving performance.



Brake Pads

The most basic components when tuning the brakes are the brake pads, which govern braking power and resistance to brake fade. The range of brake pads on offer is huge, from pads designed for the street to top-end motorsports pads. Each of these has a different optimum temperature at which braking power is greatest, and a different level of heat resistance. Choosing the wrong brake pads for your needs may not give the results you hoped for, and could even have a detrimental effect on how your car drives. Higher-end pads also wear quickly, and increase wear on brake discs due to the increased friction. When changing brake pads, as a rule they should all be changed at the same time to ensure even braking.



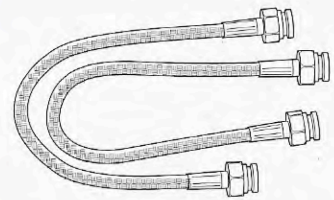
Brake Fluid

This is the operating fluid used in hydraulic brake systems. It has a boiling point in excess of 200°C in order to prevent vapour lock, but it also has extremely high moisture absorbency, meaning that it can deteriorate very easily. Brake fluids are graded by DOT grade. The boiling point increases alongside the DOT grade, but so does the tendency to absorb moisture, meaning that the fluid will degrade more easily (which lowers the boiling point). For this reason, the DOT 5 brake fluid used in racing cars needs to be replaced often. Be aware that braking power does not increase with the DOT grade.

Upgrading your brakes

Brake Hoses

Brake hoses are the pipes through which brake fluid travels. Normally they are made from rubber, but hard braking can cause them to swell, reducing responsiveness. This can be avoided by using stainless steel meshed brake hoses. These are Teflon hoses covered with a stainless mesh sheath that combines the flexibility of rubber with an increased resistance to swelling. They are fitted as standard in racing vehicles to ensure that the brakes are always responsive to driver input.

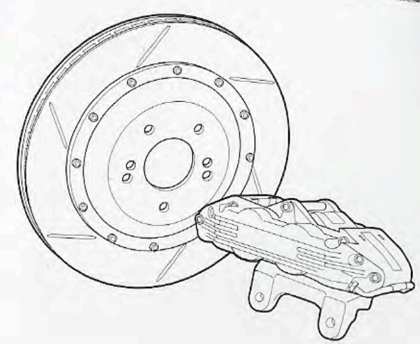


Brake Disks

The most effective way to increase braking power is to increase braking capacity. This involves using larger diameter discs to create more friction. However, large cast-iron brake discs will increase unsprung weight, which can negatively affect how your car drives. To prevent this, lightweight ceramic and carbon fibre discs are starting to become commonly available. Because brake discs become worn through use, they must be regularly replaced or resurfaced to retain their braking power.

Callipers

Upgrading brake callipers often involves replacing the entire braking system. Normal callipers press the brake pads against the brake disc from one side, and one way to upgrade them is to replace them with opposed-piston callipers, which press from both sides. Some production cars now come fitted with brakes that have six pistons, as the larger number of pistons exerts more uniform pressure on the brake pad, increasing braking power. Opposed-piston callipers are made with a mono-block construction and the high rigidity of the calliper itself provides stable braking even under harsh operating conditions.



Suspension
CHAPTER 03
Tuning & Settings

Improving Suspension

In demanding driving conditions, it's vital to be supported by well-tuned suspension to maintain stability and improve manoeuvrability. Tuning the suspension can totally transform the character of your car.

Adjusting Handling Characteristics

Tuning your suspension for sports driving inevitably means sacrificing some comfort for speed. As long as the car is on a flat surface like that of a racing circuit, the lower the body is to the ground, the lower the centre of gravity will be and the more stable its behaviour. Harder suspension makes for less wasted movement during acceleration, deceleration and turning, which keeps the handling sharp. However, if the suspension doesn't move at all, the car will not be able to deal effectively with load transfer and drive control will be extremely poor. The best solution is to make the suspension harder while also bearing in mind the degree to which weight will need to shift in all four directions. Depending on your vehicle and the driving surface, you may sometimes need to make the suspension softer in order to improve grip.

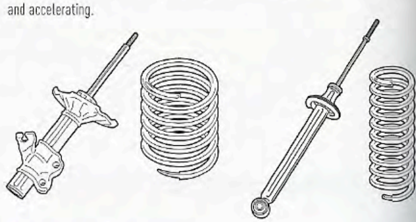
Shock-Absorbers

The objective of upgrading shock absorbers is to provide a higher damping force than the standard absorber which focuses on ride comfort. By doing so they can maintain stability of the car's behavior even at high speeds when they are under large loads, and its control will be improved. Replacement and tuning of shock absorbers should normally be performed at the same time as the springs.

Obtaining the desired level of handling

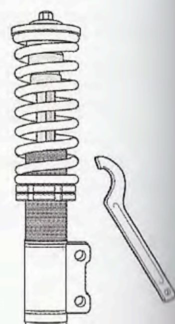
Springs

The springs improve handling by helping to achieve a low centre of gravity and are also essential in maintaining stability by counteracting roll when cornering, nose dive when braking, and squatting when taking off from a standstill and accelerating.



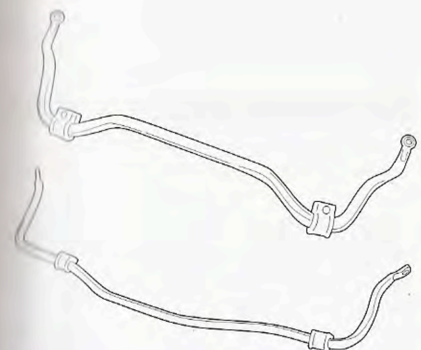
Height-Adjustable Suspension

The main type of height-adjustable suspension allows ride height to be adjusted by using shock absorbers that can increase or decrease spring length, as well as allowing the damping force to be adjusted. This allows it to be adjusted precisely to suit any situation. There are several different methods for adjusting ride height, including adjustable screws, C-rings and the use of brackets.



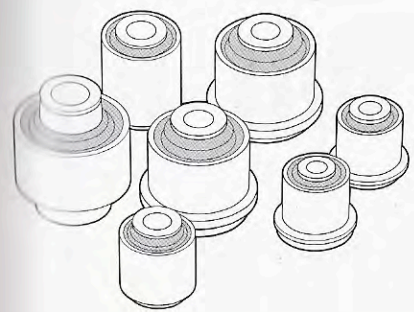
Anti-Sway Bars

Stiffening the anti-sway bars can help reduce roll even more during cornering. If the front anti-sway bar is stronger, understeer is increased; if the rear anti-sway bar is stronger, oversteer is increased.



Bushings

By using stronger bushings on dampers, suspension links and other body attachment points, as well as the bushings on a variety of linkage connections, unwanted movement of the suspension can be suppressed and linear handling and steering responsiveness is improved. Suspension bushings are generally made from resin-based materials such as rubber or polyurethane, but there are also pillow ball bushings, which use a metal sphere in the moving part.



Tyres
CHAPTER 03
Tuning & Settings

Upgrading to High-Performance Tyres

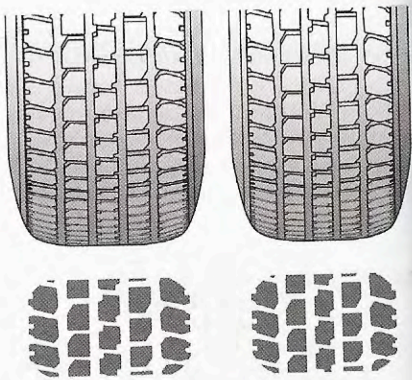
High-performance tyres are a double-edged sword - they improve grip greatly, but make control extremely difficult when their limits are exceeded. Tyres must be chosen by carefully considering how they will complement factors such as the vehicle's power and other characteristics.

Width

Increasing the width of the tyres increases the amount of tyre surface that makes contact with the ground and therefore increases grip. However, grip is not only affected by how much contact the tyre has with the ground, but also by how much load is placed on the tyre. Therefore, fitting super-wide tyres to a lightweight car may not improve grip significantly, as there may not be enough weight pressing down on them. Another problem can arise when oversized tyres are fitted to an underpowered car, in that so much power is used up counteracting the tyres' grip that the car loses speed as a result. For these reasons, the choice of tyre size should be based on the weight and output of the vehicle.

Increased Grip/Rigidity

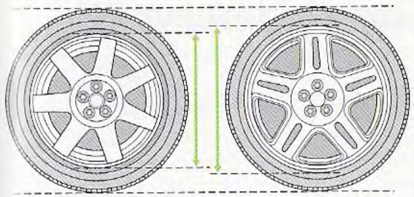
Grip and rigidity are the most important characteristics of high performance tyres. Slicks – tyres designed especially for racing – boast the best of both. The rubber compound they are made from gives excellent grip by melting slightly and sticking to the track surface when it heats up, and in order to maintain rigidity in the part of the tyre that makes contact with the road, they have no grooves. Road tyres designed for high-performance driving take a similar, if slightly less extreme, approach, using softer rubber compounds and tread patterns with very shallow grooves. However, on wet surfaces, grooves are essential to ensure that the tyres can effectively rid themselves of water, and the more there are, and the deeper they are, the better. Therefore, deciding to what degree to balance wet and dry characteristics is a key element of tyre choice.



Gripping the road effectively

Low-Profile Tyres

The profile (or aspect ratio) of a tyre describes its height compared to its width. Using low-profile tyres is a way of increasing wheel size without increasing diameter and does not necessarily mean increasing width as well. One of the main benefits of low-profile tyres is that the shorter sidewall bends less during cornering and braking, and this higher rigidity results in improvements in steering response and handling. However, lowering tyre profile increases wheel size, which can mean more unsprung weight if taken too far. Of course this can adversely affect manoeuvrability. In competitive driving, larger wheels and low profile tyres are selected to make space for larger, more effective brakes.



Compound

The rubber used to make the part of the tyre that makes contact with the ground is called the compound and dictates the tyre's grip. High-performance tyres that prioritise grip use soft compounds that adhere to the road surface better, and racing tyres even melt slightly under heat so that they can cling to the road surface better. However, while soft compounds have better grip, they wear down much more quickly and harder compounds are more durable. It is important to understand the characteristics of the compound used in order to choose the right tyre. Drivers should also be aware that rubber hardens over time, and new tyres will gradually lose grip because of this, particularly those made from softer compounds.

Tread Pattern

The series of grooves cut into the surface of a tyre is known as the tread pattern, and is designed to maintain grip in wet conditions by ridding the tyre surface of water. However, in dry conditions, these grooves reduce rigidity and can cause the surface of the tyre to sway under heavy loads, such as may occur when cornering, braking and accelerating. Because of this, the slick tyres used for racing have no grooves whatsoever, and semi-racing tyres use a minimum number of grooves that are as shallow as possible in order to maintain rigidity.

Aerodynamics
CHAPTER 03
Tuning & Settings

Improving Aerodynamics

Aerodynamic improvements are an essential part of increasing high-speed performance. Improper tuning however, can cause more problems than it solves, so an extremely delicate approach is necessary.

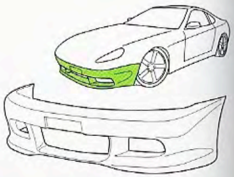
Harnessing the wind

Aerodynamic Tuning

Aerodynamic parts are often fitted for purely stylistic reasons, but when used properly, they are an essential part of tuning a car to perfection. Well tuned aerodynamics will reduce the air resistance that limits speed and the forces acting to lift the body off the ground, greatly increasing driving performance. The downforce created by aerodynamic parts is crucial in improving stability and maximising the gripping performance of the tyres, while improving control of the car. However, it is essential to balance aerodynamic tuning with the suspension and the overall car, and it is not uncommon for improper tuning to actually hinder driving performance.

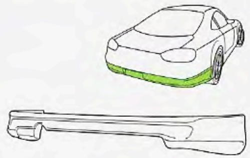
Front Spoiler

Designed to curb the flow of air underneath the car, thus reducing lift. However, in some rare cases, poorly shaped parts fitted on a car lowered to the ground can make pressurised air flow in the narrow space between the car and the ground, causing lift instead of suppressing it. In the worst cases, this can lead to complete loss of control.



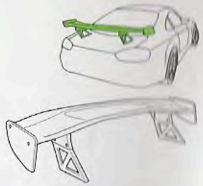
Rear Bumper Spoiler

Designed to optimise the shape of the rear bumper, preventing air turbulence behind the car and ensuring smooth airflow. The rear bumper and the rear bumper spoiler can be manufactured as one part, or the spoiler can be installed as a separate part that attaches to the bottom of the bumper. The former is called a rear bumper spoiler and the latter is called a rear under spoiler or rear skirt.



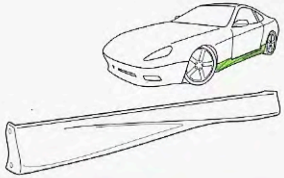
Rear Wing

Mounted on the upper part of the rear of the body, rear wing spoilers ensure that airflow is smooth around the car and prevent air turbulence. The shape of the spoiler is also designed to counter lift. The greater the size, the more downforce generated, and the more grip is increased on the rear tyres.



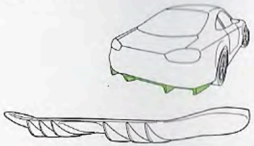
Side Spoilers

Also called side skirts or side steps, these are mounted on the left and right side sills of body. They reduce air resistance that occurs along the side of the car.



Rear Diffuser

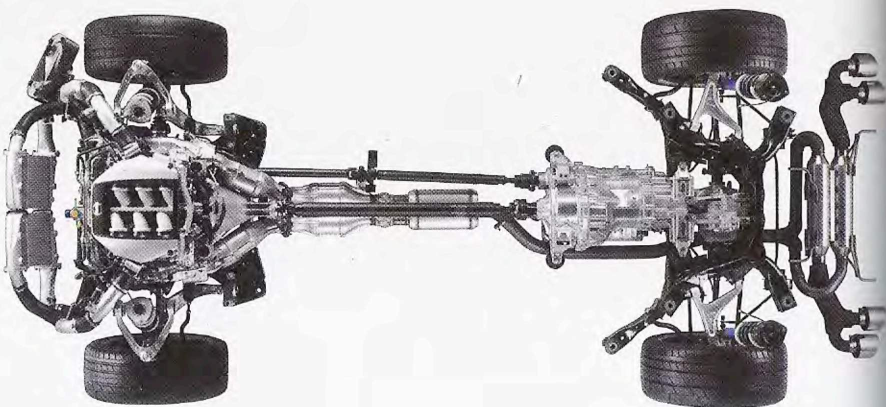
Rear diffusers are fitted beneath the rear bumper, and create negative pressure by efficiently drawing out the air from the underside of the car, thus increasing downforce. They are often used in racing cars, and the smaller the gap between the diffuser and the road, the greater its effect.



Car Characteristics
CHAPTER 03
Tuning & Settings

Changing Settings According to Car Characteristics

The possible settings when tuning a car are as varied as the cars themselves. Among the differences between cars, drivetrain layout can have one of the biggest effects on handling and vehicle behavior. It is important to understand how the different layouts behave before making any adjustments.

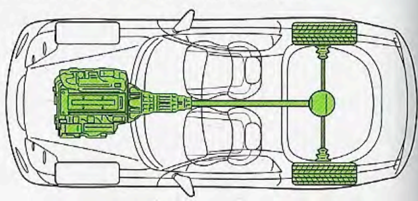


Drivetrain Layout

The drivetrain layout refers to the location of the engine - the heaviest part of the car - and the wheels to which that engine delivers its power. Different drivetrain layouts have different benefits and disadvantages, and even in highly tuned sports cars, drivetrain type remains a huge factor as it has a direct effect on how the car handles and behaves. Changing drivetrain layout is difficult, but it is possible instead to tweak a particular layout to emphasise the good points while suppressing the bad. A set-up that cleverly exploits and improves upon existing drivetrain layout, suspension and aerodynamics characteristics can create handling that is in a different class than the norm.

FR

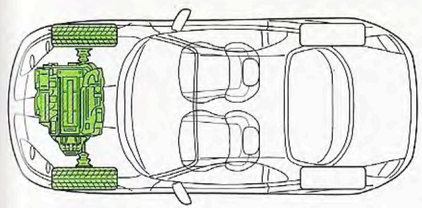
If given a good weight distribution, an FR car offers superb cornering and stability. If you want to go faster, it is a good idea to tune for increased traction at the rear wheels so that the tail does not slide out during acceleration. The front on the other hand should be tuned so that it is not prone to a "pushing understeer" condition that will prevent you from tracing the desired driving line when the load from the front is reduced during acceleration.



Compensate for weak points, improve strong points

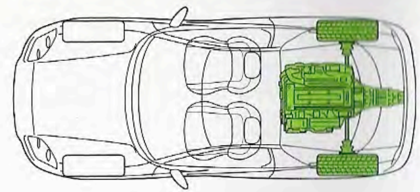
FF

In a FF the front tyres, which are both steering and drive wheels, tends to attract all the attention, but you must not forget about the rear. On a high speed course, the rear should be set for more stability, while on a course with many turns the focus should instead be placed on allowing the rear to slide out easier when letting off the pedal, enabling sharper cornering. FF cars normally use 1-way type LSDs that only activate when accelerating.



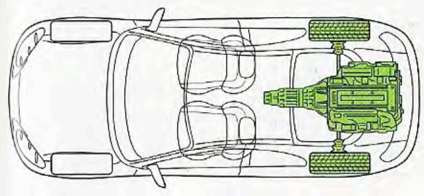
MR

Positioning the engine in the centre of the car enables good acceleration and deceleration. Turning is also sharp but when pushed to the limit, the smaller load in the front end can lead to understeer. The speed at which the rear end slides is also very quick and trickier to control. When tuning, attention should be paid to first securing its turning performance at the entry of corners, then the traction when accelerating out of a corner. Front and rear downforce should also be carefully balanced.



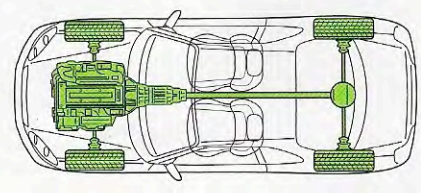
RR

A combination of the rear mounted engine and rear wheel drive gives great acceleration and deceleration, but there is even less weight on the front end than in a MR layout, making understeer during cornering even more pronounced. Also, when pushed to the limit through a corner, the heavy rear end will act like a pendulum, swinging sharply around and causing sudden oversteer. Tuning this drivetrain layout is usually a case of improving the initial turning ability upon entry into a corner.



4WD

Depending on the drivetrain layout on which the 4WD is based, the car will behave differently, but generally speaking, turning in a 4WD vehicle is more difficult due to its extremely high stability. Stability during acceleration out of a corner is extremely good to begin with, so the settings should focus on its turning ability upon the initial entry into a corner. The LSDs used on these cars are usually 1-way in the front and 2-way in the rear.



Part-by-Part
CHAPTER 03
Tuning & Settings

Basic Settings Part-by-Part

Just installing high performance parts will not make your car faster. Adjusting settings in consideration for the total balance of the car is the only way to draw out the full potential of each component and to increase a vehicle's overall performance.

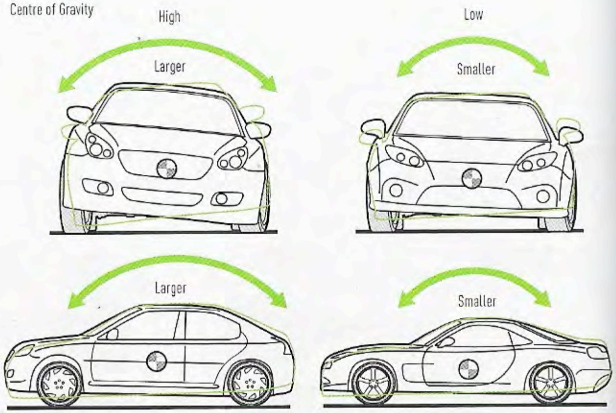
Suspension
[Ride Height/Spring Rate]

Changing Your Car's Behaviour

If road conditions are good and the surface is flat, the lower the ride height of a car is set, the lower its centre of gravity will be. This will reduce the pitching during acceleration and deceleration and minimise roll during cornering, thereby improving overall performance. The car's behaviour can also be fine-tuned by setting the front and rear suspension to different heights. For example, making the front suspension lower than the rear will push the front wheels against the road harder when entering a corner and the car will turn in more smoothly. In FF cars, this technique can be used to counteract the tendency of the front of the car to rise up when accelerating.

Spring rate also has a large impact on how a car moves. It is often thought to be the case that the harder the springs, the better, but this is not always the case. Harder springs can reduce unfavourable driving movements such as pitch, yaw and roll in the same way as reducing the ride height, but if they are too hard, kickback from the road surface will be increased to the point where it is difficult for the tyres to remain in contact with the ground and traction will be lost. For this reason, spring rate should be carefully calibrated in order to be neither too tight nor too loose for your needs.

Spring rate also has a big impact on handling. Increasing the rate at the front can lead to understeer and increasing the rate at the rear can increase oversteer, but this can be compensated to some extent by adjusting the damping force of the shock absorbers - so they must be set in pairs.



Getting the front and rear suspension balance right

Suspension
[Damping Force]

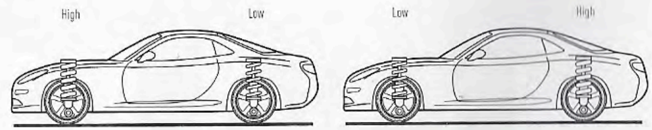
Controlling Spring Compression and Extension

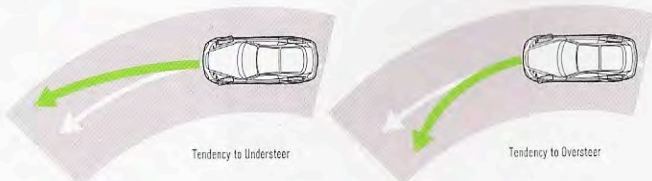
Shock absorbers control the speed at which suspension springs expand and contract when load is placed on them, and the force they exert is known as "damping force". Damping force is generated by the resistance created in oil or gas sealed inside the shock absorber's piston when it moves up and down. The higher the damping force, the more quickly the springs' movement will be suppressed, and the lower it is, the longer it will take for the movement of the springs to subside.

Damping force settings for compression and extension can be changed independently, allowing the car's behaviour and handling to be controlled more precisely. If damping force is increased for spring compression, the speed of nose dive during braking, roll when cornering and other body movements will be reduced, but the increased stiffness of the undercarriage will make the wheels more likely to leave the road under bumpy conditions, and will make it more difficult to use load transfer effectively. On the other hand, increasing the damping force for spring extension helps subside major movement changes. For example, the lifting of the front of the car when accelerating out of a corner will be suppressed by preventing the front suspension from extending immediately, maintaining the contact of the front tyres to the ground.

Handling characteristics can also be adjusted by changing the damping force for spring compression/extension between front and rear wheels. If damping force is reduced for spring compression at the front of the car, more of the car's load will tip towards the front during a turn, thus improving grip in the front and, countering understeer. Reducing damping force for spring extension in the rear will increase oversteer, and increasing it will increase understeer. As a rule of thumb, the damping force for spring compression should be set before the damping force for spring extension.

Front and Rear Damping Force
(For Spring Compression)





Suspension
[Wheel Alignment: Camber Angle]

The Positive Effect of Negative Camber

The most commonly altered wheel alignment setting is the camber angle. A negative camber is when the bottom of the wheels are spread wider apart than the tops of the wheels when viewed from the front, and a positive camber is when bottom of the wheels are pointed in towards the centre of the car.

When cornering, centrifugal force will cause the car to lean towards the outside of the turn. If the wheels are given a negative camber in anticipation of this, more of the tyre surface will be in contact with the surface when turning and better traction can be achieved. "Increasing camber angle" usually refers to increasing negative camber.

However, a negative camber has disadvantages when travelling in a straight line. The tyres are not upright on the road, so steering can be more easily disrupted by ruts or unevenness in the road surface and it can be more difficult to gain traction.

The angle of the wheels will also increase resistance, which will impede acceleration performance, and the reduced amount of tyre surface in contact with the ground will also lengthen braking distances. The more severe the negative camber, the more severe the negative effects when on the straight, so it is important to think very carefully before making any drastic changes.

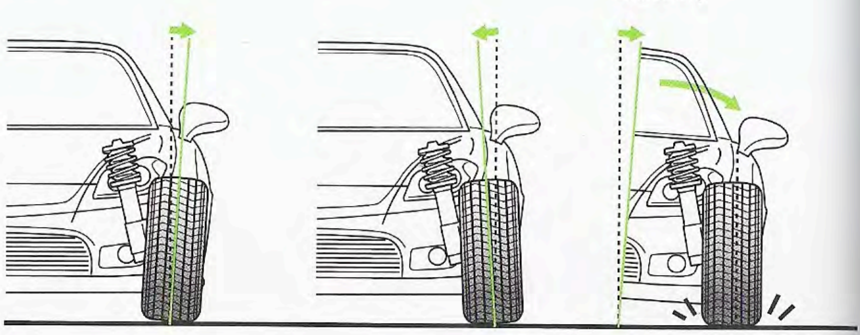
When applying negative camber, it is important to consider the effect of weight balance between the front and rear wheels when cornering. If there is a lot of load on the front of the car, the negative camber of the front wheels should be larger and that of the rear wheels should be smaller. This will reduce the risk of understeer.

A positive camber is almost never used as it reduces tyre grip and makes movements of the car oversensitive.

Positive Camber

Negative Camber

Roll While Cornering
Negative Camber Increases
Grip When Cornering



Achieving optimum grip

Suspension
[Wheel Alignment: Toe Angle]

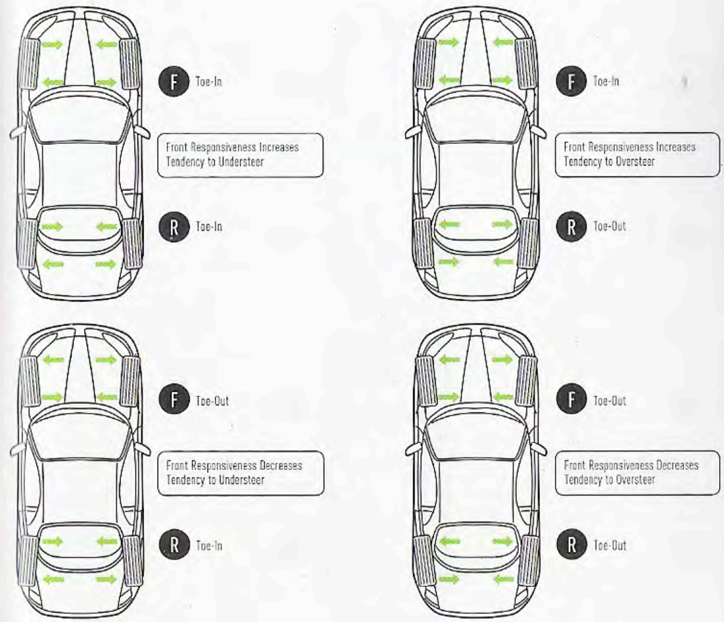
A Shallow Angle With a Deep Effect on Stability

The toe angle is the angle of the wheels when the car is looked at from above. It plays an important role in maintaining stability when weight balance between the left and right sides shifts dramatically. For example, when load moves to the outside wheel when cornering, the angle of that wheel has a huge effect on how the car behaves. The toe angle setting dictates this angle and, as such, plays an important role in maintaining stability.

"Toe-in" is when the front of the wheels face inwards. "Toe-out" is when the front of the wheels face outwards. In terms of handling, setting the front wheels to toe-in and the rear wheels to toe-out will cause a greater tendency to oversteer, while the opposite setting will cause a tendency to understeer.

The front wheels are also sometimes set to toe-out in order to make them move less erratically when cornering.

Toe angle is intricately related to wheelbase, track width, camber angle and engine power. It is often the last of these to be adjusted, and only then in order to correct slight peculiarities caused by the other factors, or to subtly tweak handling characteristics. A steep toe angle will cause a lot of resistance, so adjustments are always very small. Changes to the toe angle of the rear wheels in particular can have a large impact on drive performance and handling, so the angle of the front wheels are usually set first, and only very minor adjustments made to the rear.



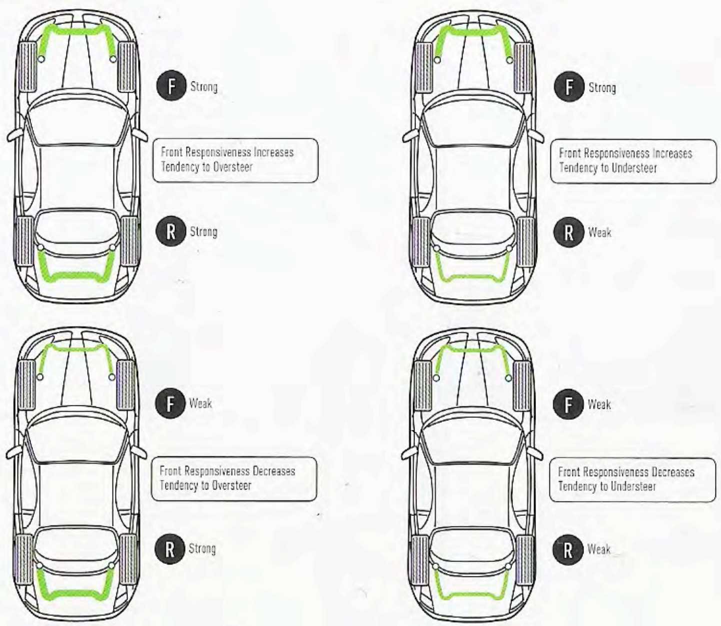
Suspension
[Anti-Sway Bar/Stabiliser Stiffness]

A Final Tweak

An anti-sway bar is a torsion bar spring that connects the lower arms of the left and right suspension. A torsion bar spring is a metal bar that utilises the resistance of twisting force placed upon it. When the suspension on one side moves during cornering, the resistance of the suspension on the other side counteracts that movement, reducing roll, and thereby keeping more of the tyre surface in contact with the ground. The stiffness of this bar is represented by a spring rate similar to that of a suspension spring, and increasing the stiffness of the front anti-sway bar will improve steering response.

When adjusting the anti-sway bar, it is important to not set the spring rate higher than that of the suspension spring. If the anti-sway bar is stronger, the suspension spring will be too weak to overcome it and when weight moves to the outside wheel, the inside suspension will lift up with the anti-sway bar, causing the inside wheel to lift off the track and traction to be lost.

It is also possible to adjust handling by altering the spring rates of the front and rear anti-sway bars, but these kinds of adjustments should usually be made by just changing the spring rate of the suspension springs and the damping force of the shock absorbers. Adding anti-sway bar stiffness to this equation overcomplicates things and makes it very difficult to achieve the desired result. Anti-sway bar stiffness adjustments should be seen as a final tweak rather than a tuning method in themselves.



Drivetrain
[LSD]

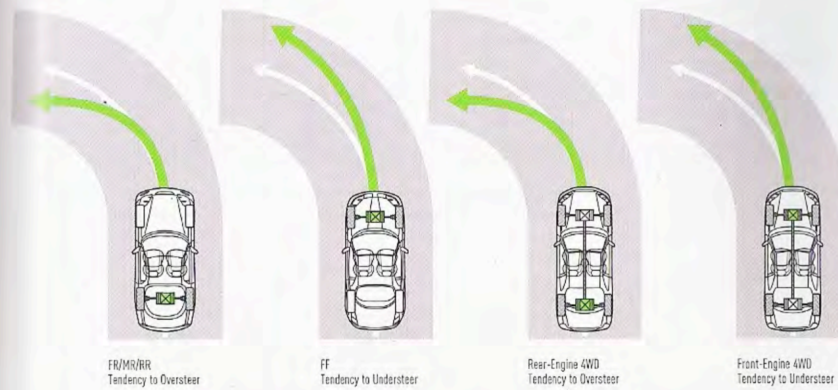
Changing the Limit Changes Manoeuvrability

Initial torque decides the point at which the LSD kicks in. The higher it is, the more easily the LSD will lock and the more responsive acceleration will be. The lower the initial torque, the more slowly the LSD will take effect.

Generally speaking, increasing the initial torque will accentuate the handling peculiarities of a vehicle's drivetrain layout. Therefore, oversteer will be increased in rear-wheel drive cars and understeer will be increased in cars with front-wheel drive. Although this improves traction in both cases, it will make turning more difficult. As such, initial torque adjustments should be made with the desired handling requirements in mind.

Another setting that can be adjusted is how the LSD behaves during acceleration and deceleration. The acceleration setting governs the effectiveness of the LSD when stepping on the accelerator and, the stronger it is, the more drive power is transmitted to the wheels and the more quickly the car will be able to clear corners. However, this will also accentuate any handling peculiarities, and getting the car to point in the direction needed to exit the corner may require some skill.

The deceleration setting governs the effectiveness of the LSD when the accelerator is released. The stronger it is, the more stable it will be upon entry into a corner while braking. This allows you to go into the turn very fast, because you can keep braking longer than you would otherwise. However, this makes turning more difficult and is only recommended for advanced drivers who are skilled at compensating for initial understeer.



Adjusting cornering behaviour

Drivetrain
[Gear Ratio]

Maintaining Power with a Close Ratio

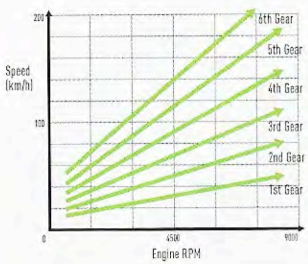
Race cars have to drive on all kinds of circuits, from winding tracks with many corners to tracks that feature long, high-speed straights. In order to get the best out of your engine on a particular course, it is often necessary to change the gear ratio of your drivetrain. This usually involves changing both the final gear and the gears of the transmission.

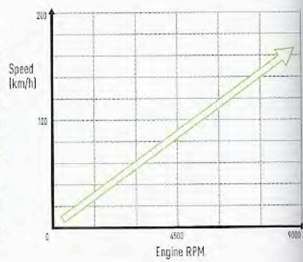
When driving on a track with lots of low and mid speed corners, your focus will need to be on accelerating out of the corners rather than achieving high speeds. At times like these, a transmission consisting of gears of similar ratios will allow you to stay more easily within the powerband. This kind of gear setup is known as a "close ratio".

On the other hand, on a course featuring lots of long straights that emphasise high speed, you will want a setup that increases top speed by using smaller ratios for 5th and 6th gear. This kind of gear setup is known as a "wide ratio".

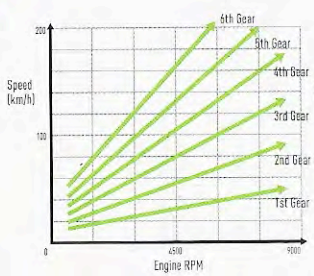
The gear ratio of the final gear affects how the transmission as a whole behaves. If the final gear is made smaller with the same set of transmission gears, acceleration will be improved but top speed will be reduced, whereas a larger final gear will increase top speed at the expense of acceleration. When you first start adjusting gears, you should just change the final gear for an easy adjustment. You want to set the gear so that the engine will reach the rev limit in the last gear of the transmission, just by the end of the straightaway on the track.

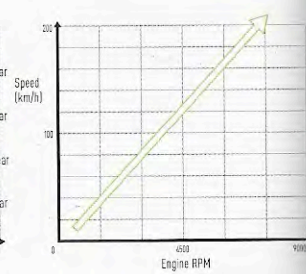
On a course with lots of corners, bringing the ratios of all the gears closer together puts the focus on acceleration performance.





On high-speed circuits with long straights, increasing gear ratios will put the focus on increasing top speed.





Aerodynamics
[Downforce]

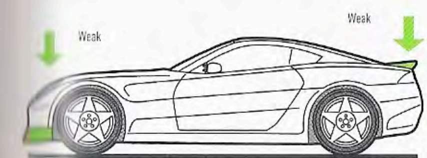
Improving High-Speed Performance

It is impossible to ignore the effects of air when driving at high speed. These effects can broadly be divided into two categories: air resistance, which limits top speed, and lift, where the movement of air picks the car up off the ground. These two factors are closely related: reducing air resistance increases lift, and reducing lift increases air resistance. Therefore, a careful balance needs to be struck between the two.

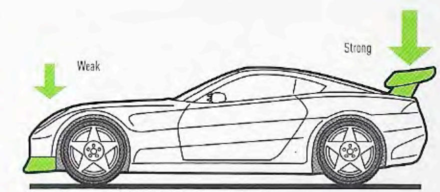
A key concern when tuning to deal with air movement at high speed is how best to exploit downforce. Downforce is the force exerted when air resistance pushes down on the car, improving contact with the road. An increase in downforce will reduce top speed, but will increase stability when cornering and improve cornering speed, especially on high speed corners. Reducing downforce, on the other hand, will reduce cornering speed, but will allow the car to move more quickly on the straight.

The amount of downforce needed is dictated by the nature of the course, and although it might seem so, having strong downforce from the start will not produce a good setting. The ideal way to set a car is to perform various settings with the minimum downforce, then gradually increase it according to the importance of the high speed corners. For small displacement cars, the best approach is usually to maximise top speed by reducing downforce to zero.

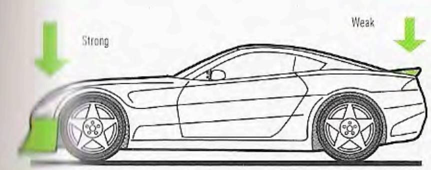
Variations in front and rear downforce can also be used to alter handling characteristics when negotiating high-speed corners. Increasing downforce on the front end will increase grip on the front wheels, increasing oversteer, whereas stronger downforce on the rear will have the opposite effect, increasing understeer. Adjustments of this type can make all the difference on high-speed circuits.



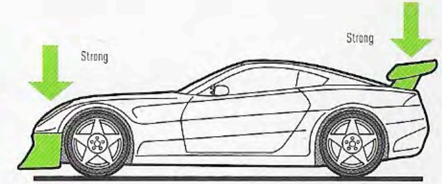
Top Speed Increases
Control Decreases



Top Speed Decreases Slightly
Tendency to Understeer



Top Speed Increases Slightly
Tendency to Oversteer



Top Speed Decreases
Control Increases

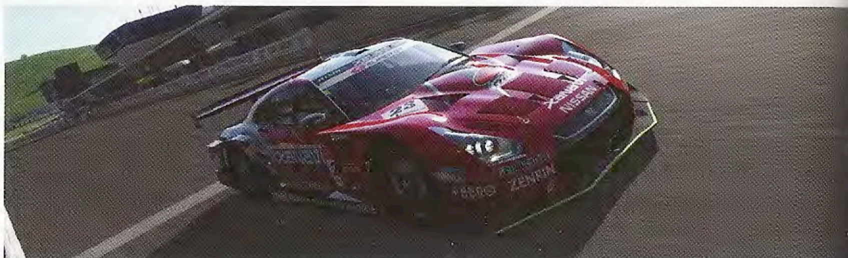
Specific Situations

CHAPTER 03
Tuning & Settings

Settings for Specific Situations

One very important reason for adjusting your car's settings is to deal with a specific course or specific conditions. A few quick suspension and drivetrain tweaks can make a surprising difference to how your car handles a particular track.

Getting the best performance



High-Speed Circuits

Improving Top Speed

The ideal settings for a high-speed circuit are those which allow the car to take high-speed corners as fast as possible. The suspension and shock absorbers should be stiff and the ride height low. However, if the ride height is so low that the springs cannot move sufficiently, the suspension will be too hard to absorb the impact of bumps and undulations in the road, cancelling out any beneficial effects. If you use stiffer suspension springs, reducing the stiffness of the anti-sway bars will create a little roll that will keep the wheels in better contact with the road. If, on the other hand, you soften the springs a little in order to deal with an uneven road surface, stiffening the anti-sway bars will help combat excessive roll. Basically, the idea is to have your anti-sway bars compensate for the shortcomings of your springs.

Wheel alignment is also important. Increasing the rear toe-in angle is a good way of improving stability. The camber should be at least slightly negative, but you also want as much of the tyre as possible to be in contact with the track when driving fast on the straight and when braking hard, so it's best not to go overboard.

As far as gear ratios are concerned, the aim is the same as always: to keep the car within the powerband as much as possible. The final gear should be set to a ratio that allows the top gear to just reach redline by the end of long straights. As for downforce, the minimum possible amount should be used in order to maximise speed on the straight, but you want to make sure that stability is not lost when cornering and braking.

Suggested Suspension Settings

		FRONT	REAR
Ride Height		Low	Low
Shock Absorber	Extension	Strong	Strong
	Compression	Strong	Strong
Spring Rate		Hard	Hard
Wheel Alignment	Toe Angle	0	In
	Camber Angle	Negative	0
Anti-Sway Bar		Hard	Hard

* Depending on the car, these settings may not be possible.

Technical Courses

Effectively Transferring Power to the Road

For a technical course with a lot of tight corners, the goal is to set up a car that can turn quickly and has the ability to accelerate out of corners with a minimum loss of power. The first thing to do is set the ride height to an appropriate level for the course, which should be as low as can be achieved without causing problems.

The front springs should be softened and the rear springs stiffened (only moderately in rear-wheel drive cars) in order to enable better turning, and the shock absorbers set with the same aim in mind. Alignment-wise, the front wheels should be set with a slight toe-in angle if the driver wishes to prioritise initial responsiveness when cornering, but with less toe-in if the emphasis is more on drive feel at and beyond the clipping point. Negative camber should be used in moderation, as traction needs to be maintained when braking and cornering. The transmission gearing should be set with a close ratio to maintain revs rather than prioritising top speed, and the final gear ratio should be low to allow quick acceleration.

If full-scale engine tuning is possible, the focus should be on achieving maximum torque at low and medium speeds in order to boost acceleration out of corners rather than on achieving maximum power at high revs. Downforce on both front and rear should be as high as possible, as the aerodynamics of the car should support stability during cornering rather than improving top speed.

Suggested Suspension Settings

		FRONT	REAR
Ride Height		Low	High
Shock Absorber	Extension	Strong	Weak
	Compression	Strong	Weak
Spring Rate		Hard	Weak
Wheel Alignment	Toe Angle	0	In
	Camber Angle	0	0
Anti-Sway Bar		-	-

* Depending on the car, these settings may not be possible.

Countering Understeer

Understanding Where the Car Refuses to Turn

Start by identifying when understeer occurs, whether it is on entry to a corner, near the clipping point or when accelerating away. If understeer occurs on entry to a corner, the grip of the front tyres needs to be increased as much as possible. This can be achieved by softening the front suspension springs and increasing the extension side of the shock absorber, while reducing it for spring compression in order to encourage load to move forward. As well as suspension-related factors, an over-sensitive LSD can also cause understeer at this stage of a corner, and lowering the LSD's lock rate and initial torque can go some way to rectifying this. If you are using a 2-way LSD (one which takes effect whether the accelerator is pressed down or not) in a rear-wheel drive car, try changing it for a 1-way system that does not take effect when decelerating.

On courses with high-speed corners, increasing front-end downforce to improve the grip of the front wheels can also be effective. If understeer is occurring when approaching the clipping point, negative camber should be increased in order to ensure that more of the tyre is in contact with the ground. Reducing rear-wheel toe-in can also help to balance grip and, if possible, increasing track width at the front end can also be effective.

If understeer occurs in rear-wheel drive cars when accelerating out of corners, it can be counteracted by decreasing ride height at the front, increasing the damping force for extension on the front shock absorbers and increasing it for compression on the rear. If it occurs in an FF car, it can be combated by increasing the effect of the LSD.

Suggested Suspension Settings

		FRONT	REAR
Ride Height		Low	High
Shock Absorber	Extension	Strong	Strong
	Compression	Weak	Strong
Spring Rate		Weak	Hard
Wheel Alignment	Toe Angle	In	0
	Camber Angle	Negative	0
Anti Sway Bar		Weak	Hard

* Depending on the car, these settings may not be possible.

Countering Oversteer

The Trouble With Rear-Wheel Drives

FF and 4WD cars rarely suffer from oversteer, this problem almost exclusively affects rear-wheel drive cars. If you are aiming simply to have maximum control of oversteer, for example in a drift event, then both the front and rear suspension should be stiffened in order to improve control over how much the rear end slips out. However, in a time trial or similar track racing event, you will need to take measures to maintain traction in order to keep the car moving forward. The main reason for unwanted oversteer is the loss of rear-wheel traction when the accelerator is applied, which causes drive power to be wasted on moving sideways rather than accelerating.

Spring rate and damping force can be tuned to counter this effect. The rear springs should be softened, and the damping rate of the shock absorbers decreased for compression and increased for extension. It can also be beneficial to reduce the stiffness of the rear anti-sway bar in order to increase load movement onto the inside wheel. If possible, rear track width should also be increased. If the front suspension is too soft, weight from the rear can shift forward too easily, so the front suspension should be stiffened in order to improve grip at the rear.

If there is a rear spoiler, the angle should be increased in order to increase downforce. However, this will mean a slight loss of top speed.

Suggested Suspension Settings

		FRONT	REAR
Ride Height		High	Low
Shock Absorber	Extension	Strong	Strong
	Compression	Strong	Weak
Spring Rate		Hard	Weak
Wheel Alignment	Toe Angle	-	In
	Camber Angle	-	Negative
Anti Sway Bar		-	Weak

* Depending on the car, these settings may not be possible.

Wet Conditions

Getting the Best Out of Your Tyre

As you might expect, when it rains, the friction coefficient (μ) of the road surface is reduced, and grip along with it. Let's look at some settings that can be tweaked in order to deal better with wet conditions.

Spring rate, damping force and anti sway bar stiffness should all be set lower than they would be in dry conditions, and in some cases, the rear anti sway bar can be removed entirely. Stiff suspension will make it harder for the wheels to remain in contact with the ground and may cause the car to slide out suddenly. Hard suspension improves grip when the grip of the road is good, but in wet conditions, where grip is poor, the softer the suspension the better. The camber angle should be decreased slightly more than in dry conditions to ensure that more of the tyres maintain contact with the ground during acceleration and deceleration.

In cars where aerodynamic adjustments are possible, front and rear downforce should be increased in order to maximise grip. One of the simplest wet weather tweaks is to adjust your tyre pressure. In heavy rain, increasing tyre pressure will put less of the tyre surface in contact with the ground increasing load on the part of the tyre that is touching the ground and thereby preventing hydroplaning. Conversely, in light rain, reducing tyre pressure can improve performance. Altering the air pressure of the front and rear tyres is a quick and easy way to fine-tune the amount of grip they achieve, and is usually one of the first adjustments made.

If full-scale engine tuning is possible, the emphasis should be placed on low- and mid-range torque rather than top-end power. Relying more heavily on electronic control devices can also improve wet-weather performance, and it can be surprising to see how much difference an electronic braking-control system can make.

Suggested Suspension Settings

		FRONT	REAR
Ride Height		Low	Low
Shock Absorber	Extension	Weak	Weak
	Compression	Weak	Weak
Spring Rate		Weak	Weak
Wheel Alignment	Toe Angle	In	In
	Camber Angle	Negative	Negative
Anti Sway Bar		Weak	Weak

* Depending on the car, these settings may not be possible.

Gravel

Improving Control

The most important thing when setting a car up for gravel driving is to allow for flexible control. The condition of unpaved surfaces is often unpredictable, and altering your driving line even slightly can take you over areas the friction coefficient of which is completely different. Cars will also kick up sand, dust and gravel as they drive, completely changing the nature of the road surface for those that follow them. If a car is tuned solely to push the limits of its performance as it would be on a surfaced track, it won't have the flexibility to deal with sudden changes in the road surface.

One way of tuning for road surfaces of this kind is to aim for a set-up that will cause the front of the car to turn in when the driver's foot is taken off the accelerator, but which will have neutral steering (i.e. no oversteer or understeer) when the accelerator is applied. This is what might be called an "oversteer" set-up, which allows turning to be controlled to some degree by acceleration. It can be achieved by using a 2-way LSD and adjusting the balance of braking power between the front and rear.

Understeer and oversteer countermeasures can be approached in the same way on gravel as on paved roads. Ride height depends entirely on the road surface - lower is still better, but bumps, rocks and other obstructions mean a higher risk of damaging the car. On courses with jumps, the aerodynamics should be balanced so that the car maintains a good position when airborne. Engines should be tuned for maximum response rather than maximum power.

Generally speaking, achieving good speed on gravel uses the same set of driving techniques as on the track.

Suggested Suspension Settings

		FRONT	REAR
Ride Height		High	High
Shock Absorber	Extension	Strong	Strong
	Compression	Strong	Strong
Spring Rate		Stiff	Stiff
Wheel Alignment	Toe Angle	In	
	Camber Angle	Negative	Negative
Anti Sway Bar		Weak	Stiff

* Depending on the car, these settings may not be possible.

The Next Generation of Power Sources

In the last decade or so, the world of driving has changed dramatically. The era of driving performance taking precedence over all else is approaching an end and the focus has increasingly switched to technologies aimed at enabling the automobile to exist in harmony with the planet. Here, we'll look at some of the energy sources that may well carry us into the next generation, and take a glimpse into the future of the automobile and its development.

The automobile is celebrating its 120th birthday. During its lifetime, numerous technologies have come into existence, evolving and expanding this endlessly versatile mode of transport. However, as cars have spread like wildfire throughout the globe, the issue of their impact upon the environment has become harder and harder to avoid. As fossil fuels edge ever closer to depletion, one question is being asked which will affect the fundamental nature of the automobile: what will power the cars of tomorrow?

In an attempt to answer this question, automobile manufacturers are experimenting with various options, but as yet no definitive solution has been reached. Here, we'll be giving you a rundown of the various challenges they are facing. But before we introduce the next generation of power sources, it will first be necessary to take a look at the evolution of petrol and diesel internal combustion engines themselves. Despite accusations that they are behind the times, petrol and diesel engines have not yet reached the peak of their evolution, and are likely to continue to play a significant role for a while to come.

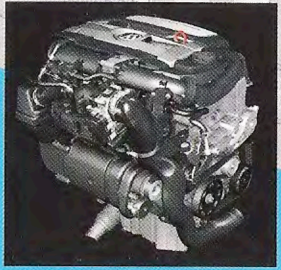
The key lies in achieving further efficiency and downsizing. In terms of efficiency, automobile manufacturers claim to be able to raise current standards of thermal efficiency – approximately 25% for petrol and 30% for diesel – to as much as 35%, a level on a par with that of a hybrid engine.

One example of this claim is Mazda's SKY-G and SKY-D range of next-generation engines, announced at the 2009 Tokyo Motor Show. Both engines feature reduced mechanical resistance, improved direct fuel-injection systems and advanced variable valve timing. In fact, the SKY-G-equipped "Kiyora" concept car achieves 32 kilometres to the litre – a super-low level of fuel consumption, equivalent to that of a hybrid car.

Meanwhile, the concept of downsizing involves creating lower-displacement engines with the aid of superchargers and other combustion aids. Volkswagen's 2-litre Golf and Scirocco models, both fitted with 1.4-litre supercharged engines, are good examples and have improved fuel consumption by up to 20%. Furthermore, Volkswagen, Daihatsu, and Fiat recently announced two-cylinder engines one after another, sparking a new trend towards compact cars that is receiving a fair amount of attention. From here on in, the movement towards downsizing looks to become standard practice, and may even expand to include large saloons and sports cars.

As you can see, there is life in the internal combustion engine yet, and it's clear that this technology isn't quite ready to retire.

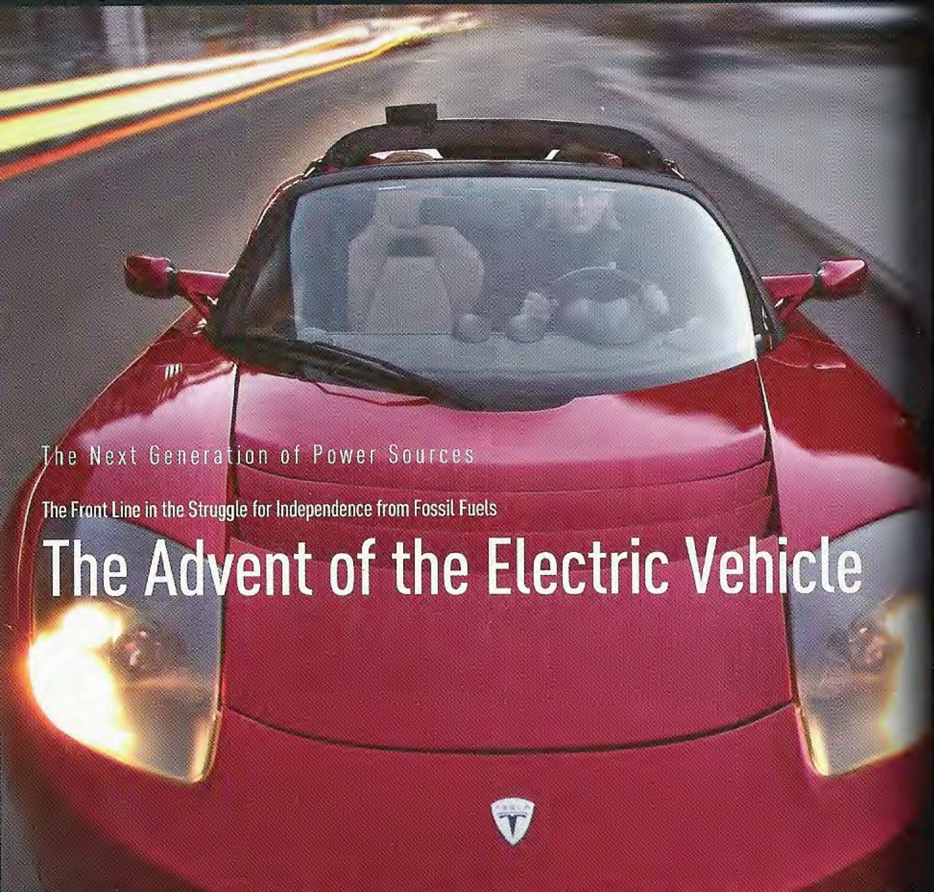
SKY-G: Mazda's next-generation engine. Several state-of-the-art technologies, including reduced mechanical resistance, direct fuel-injection and variable valve timing have been condensed into one neat little package.



The 1.4-litre Twincharger engine, fitted by VW to its Golf and other models. In a good example of the trend for downsizing, low displacement is compensated for with a supercharger.

The 'DiesOtto' engine introduced by Mercedes in 2007. High efficiency is achieved through self-ignition, made possible by super-compressing petrol.

The next generation of power sources



The Next Generation of Power Sources

The Front Line in the Struggle for Independence from Fossil Fuels

The Advent of the Electric Vehicle

When the engine-powered automobile first appeared, many people believed that steam engines or electric motors were safer, and held more promise. Fast forward 120 years. The golden age of the engine has passed and the electric vehicle (EV) is making a comeback. In 2009, Mitsubishi released its i-MiEV to the Japanese marketplace. At around the same time, Subaru introduced its Plug-in Stella and, in 2010, Nissan is due to launch its Leaf electric car. In addition to the vehicles themselves, related technologies such as batteries are also undergoing huge development in order to make the electric car a viable means of modern transportation.

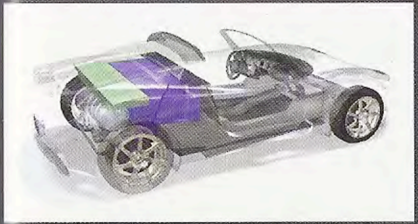
The basic structure of the electric automobile is simple. Electricity drawn from an external source is temporarily stored in the battery, then used to power the motor and turn the wheels. Unlike the petrol engine, an electric engine does not need complicated parts such as a radiator to cool it or a complex air-intake system. Currently, more than 20,000 components are needed to build an average car, but with the electric car this number would dramatically decrease. One particular sports car leads the way in the electric vehicle boom - the Tesla Roadster, made by Tesla Motors, which hit the roads in 2008.

The electric car may still be strongly associated with short-range city driving, but Tesla has gone out of its way to equip the Roadster with everything needed to be considered a genuine sports car. The exterior is based on the Lotus Elise and the additional weight of the battery is offset by a carbon-fibre body. In fact, despite being fitted with a 450kg lithium-ion battery, the fact that the Roadster has kept its weight as low as 1350kg is astonishing. In addition, by installing the battery behind the front seats, the negative effect on driving performance has been kept to a minimum.

The battery power output is 215kW (approximately 292 ps/HP). It produces a torque output of 370Nm (37.7kgm), which is equivalent to a 3.5-litre petrol engine. Its performance is truly superb, and it achieves 0-100km/h in 3.9 seconds, with a top speed limited at 125mph (approximately 200km/h). On a single charge, driven by an average American, the car will cover a distance of 236 miles (377km).

The Tesla is proof that electric vehicles are a genuine possibility. There are those who believe that enjoyable driving is the sole domain of petrol engines, but take a ride in the Tesla Roadster and it becomes obvious that this is not necessarily the case.

For electric vehicles to achieve large-scale popularity there are still some obstacles to be overcome, such as improving batteries and the infrastructure required to charge such vehicles. Nevertheless, events such as the capital tie-up announced between Tesla Motors and Toyota in 2010 bode well for the future. Meanwhile, the introduction of high-tech electricity networks known as "smart grids" has become a priority in many countries, and investigations have begun into making provisions for electric vehicle charging stations as part of these new energy networks.



A transparent view of the Tesla Roadster. The car boasts a highly functional layout, with the heavy battery positioned directly behind the seat, and the motor positioned close to the rear wheels.

Subaru Plug-in Stella

This EV was launched by Subaru in June 2009. The battery is sized with city commuters in mind and is designed to have a short charging time.

Mitsubishi i-MiEV

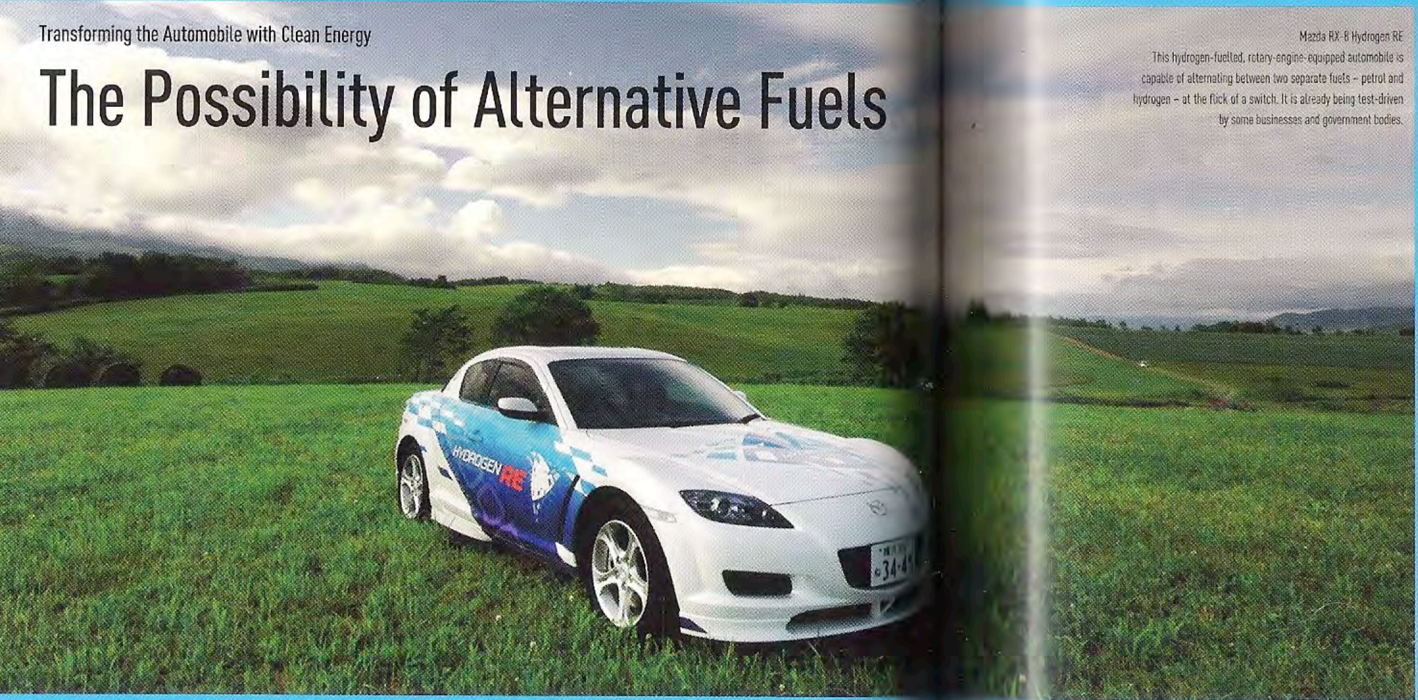
This highly accessible EV was announced in June 2009 and went out for sale to individuals the following month. The battery is fitted under the floor to achieve a low centre of gravity.

Nissan Leaf

Nissan is due to launch this EV, intended for the global mass market, at the end of 2010. It is equipped with the latest in lithium-ion battery technology to achieve a greater cruising range.

Transforming the Automobile with Clean Energy

The Possibility of Alternative Fuels



Mazda RX-8 Hydrogen RE
This hydrogen-fuelled, rotary-engine-equipped automobile is capable of alternating between two separate fuels – petrol and hydrogen – at the flick of a switch. It is already being test-driven by some businesses and government bodies.

There is another alternative other than electricity that has the potential to help reduce or eliminate our dependence on fossil fuels. That alternative is hydrogen. As the name suggests, a hydrogen car is an automobile which runs on hydrogen, and since the existing structure of the internal combustion engine can be used more or less as it is to make a hydrogen engine, automobile manufacturers are eager to continue research into this area. Hydrogen-fuelled cars do not put stress on the environment in the same way as petrol-fuelled cars. Burning hydrogen produces only water and a miniscule amount of nitrogen oxides.

One reason that hydrogen is being hyped as the fuel of the future is that, as an element of water and various fossil fuels, there is an inexhaustible supply. Moreover, it should not be overlooked that, of the various fuel types, it has the highest energy value per unit weight and is a recyclable energy that converts back to water after use. The automobile companies leading the way with hydrogen engines are Germany's BMW and Japan's Mazda. Since February 2007, Mazda has made its RX-8 Hydrogen RE available for lease, and BMW is conducting numerous tests aimed at putting the world's first hydrogen car, the "Hydrogen 7", into production. Mazda's hydrogen car uses a rotary engine in order to leverage a special characteristic: backfires rarely occur, since injection and combustion take place in separate locations.

And that's not all. Another application of hydrogen as an energy source that has caused great excitement is the hydrogen fuel cell. This is a system that generates electricity by causing a chemical reaction between hydrogen and oxygen. Since it uses the inexhaustible resources of hydrogen and oxygen, and produces only water upon reaction, this system is the subject of large-scale research. Many people believe that the fuel-cell electric vehicle (FCEV) will supercede hybrid, electric and hydrogen cars. Meanwhile, there is one question concerning hydrogen to which a clear answer has yet to be found: how should it be produced and stored?

Presently, the most commonly cited method is to extract hydrogen from naturally occurring gases and store it under high compression, and although several alternative methods have been proposed, none has yet found serious backing. As such, many people believe that the widespread use of hydrogen as a fuel may not occur until as late as 2050.

That's not to say that automobile manufacturers aren't doing their best. Numerous manufacturers have already announced fuel-cell concept cars. Amongst these, the FCX Clarity unveiled by Honda in 2007 is close to being perfected and has already been made available for experimental lease in America and Japan.
In addition, the idea of using fuel cells in hybrid vehicles or in EV subsystems is being investigated and, if this becomes a reality, it is very likely to spark the widespread use of fully-fledged fuel-cell cars.

The Next Generation of Power Sources

The idea of using hydrogen – a clean, abundant, and manageable fuel – to power automobiles is edging ever closer to reality. The BMW Hydrogen 7, Mazda's hydrogen-rotary-engine-equipped RX-8, and the various hydrogen-fuel-cell-equipped vehicles, including Honda's FCX Clarity, are worth keeping an eye on in future.

A More Pragmatic Next-Generation Power Unit

Taking Hybrids to the Next Level

In 1997, the Toyota Prius was launched as the first mass-produced hybrid car. Over a decade has gone by since then, and hybrid cars have now found themselves a real role in the marketplace. Currently, the Toyota Prius and Honda Insight lead the hybrid field, but in February 2010, Honda launched its CR-Z sports hybrid, injecting new life into the eco-friendly automobile arena by emphasising enjoyable driving. Meanwhile, the Prius is finding a new lease of life as a plug-in hybrid which can be charged from home.

The other motor industry giants are not taking this lying down. Mercedes and BMW are introducing hybrids to their respective flagship lines, the S-Class and 7 Series. The design concepts go beyond low fuel consumption alone and utilise the motor as a supercharger to give the engine a performance boost. The Audi A8 is also due to be launched shortly and is set to become an exceptional eco saloon, combining luxury with a four-cylinder, 2-litre turbocharged engine.

In the US, the GM Volt is currently on standby. The Volt was originally designed as an EV, but in order to extend its range, an engine was added and it became what has been termed a range-extended electric vehicle (REEV). Driven as an EV, it has a range of 40 miles, after which it becomes a series-hybrid, using electricity generated by the engine.

The hybrid wave has even swept as far as sports cars. At the 2010 Geneva Motor Show, Porsche announced three hybrid vehicles at once: the new Cayenne, the 911 GT3 Hybrid and the 918 Spider. The Spider does away completely with the traditional hybrid image and is a highly anticipated and extremely high-end luxury sports car. Ferrari also launched its 599 Hybrid at the Geneva Motor Show, proving that these vehicles are now making real inroads into the world of performance driving.

A charging function was added to the Prius to create the Prius Plug-in Hybrid, with strengthened EV performance (left). To the right is the E300 BlueTec Hybrid, Mercedes' diesel hybrid, which is due to be launched in 2011.

The CR-Z (left) sets itself apart from existing hybrids with its superior performance, handling and styling. On the right is VW's 2-seater hybrid, the L1. Super-low fuel consumption is the main selling point of this 800cc, 2-cylinder diesel hybrid.

Tuning

ALL LINKS CLICKABLE

Settings

CHAPTER

04

Apex [The Gran Turismo® Exclusive Magazine]

Photo Mode

Capturing the Moment

FOTO
SLS
AMG

Angle and Composition

The Information Captured in the Field of View is Everything

A great photograph captures an instant in time that can never be revisited. Its beauty and impact live on for eternity, capturing the hearts of all who see it. Achieving this, not by chance, but by design, makes the act of "freezing a moment" all the more satisfying.

Capturing that sought-after moment requires a diverse range of skills, and this is never more true than when photographing a car, which is a fairly sizeable subject. There are numerous points to be considered before the shutter is pressed. This section gives advice on the basic techniques needed to take great motoring photographs.

The first point to consider is where the best place to photograph the car might be. There's nothing wrong with using whichever location happens to be most convenient, but for a truly impressive photograph, it is worth going that extra mile to find the perfect backdrop.

When deciding upon your location, one point to consider is how much information you want to pack into the field of view. In order to do this, it is important to identify what kind of scenery you can afford to leave out of the picture by carefully studying the location. As mentioned earlier, a car is a substantial object, and as such, getting the right sense of space is paramount, and means carefully scrutinising scenery and nearby structures that could potentially add to or detract from the photograph. The car must always remain the centre of attention, which means open areas make ideal backdrops. Being mindful of positioning and background and arranging nearby structures as simply as possible ensures a striking composition in which the subject stands out. The fact that professional photographers spend huge amounts of time locating the ideal backdrop for their shots should give you some idea of just how important it is.

Once the location is settled, attention should be paid to the angle of view and the composition. The angle of view will depend on the lens, but when starting out, it is best not to rely too heavily on wide-angle or telephoto lenses. The reason for this is that using such lenses gives too much freedom, and makes it difficult to leave out elements of scenery. If possible, you should avoid changing the focal length in order to change the view. Instead, it is better to move the position from which you take the photo, so that you learn to gauge the ideal distance between yourself and the subject.

When photographing a car, angle and direction can dramatically alter the impression given by the resulting picture. There are various ways to present a subject depending on the desired result, but generally speaking the angle which provides the most balanced view of a car is a side-front ratio of 7:3. Many of the photographs that you'll come across in catalogues and elsewhere are shot from this angle, and 7:3 is considered the golden ratio by many car photographers.

Height is also an important factor. Even with the car positioned in the same location and facing in the same direction, it will look different depending on whether it is shot from a high or low angle. First, look carefully through the viewfinder from a standing line of sight to get an idea of the overall look of the car. Generally, shooting from a low angle makes the centre of gravity appear lower, portraying a sense of stability, and giving the idea that the car will hug the road. When photographing a sports car, shooting from a low angle somewhere near the road surface conveys a more powerful image. On the other hand, shooting from a high angle will give a good three-dimensional composition which clearly shows the details of the car, but won't give the same sense of stability as a low-angled shot.

[1/125 • F5.6 • 50mm]

The car is still the main focus, but the photograph also skillfully captures the background structures to give a truly stunning image.

Angle of View

The angle over which a lens captures an image is known as the angle of view. Wide-angle lenses broaden this angle, whilst telephoto lenses narrow it. Lenses should be chosen based on their particular characteristics.

[1/250 • F4 • 50mm]

[1/250 • F4 • 135mm]

[1/250 • F4 • 300mm]

Composition

Composition is an important element not only of photographs, but also of paintings. Try to compose an image based on the arrangement and balance of objects and colours. Techniques include triangle, radial, and S-curve composition.

[1/125 • F11 • 27mm]

Depth of Field & Filters

Techniques for Adjusting the Amount of Visual Information

Once you've mastered the basics, it's time to take your photography to the next level. You should aim to familiarise yourself with the following techniques: ❶ Rule of thirds, ❷ Triangle composition, ❸ S-curve composition, ❹ Diagonal composition, ❺ Contrast composition.

❶ The rule of thirds involves splitting the field of vision into three equal parts, both vertically and horizontally, and arranging the compositional elements around the lines and intersections. Using this simple technique can save many a photograph from mediocrity. ❷ Triangle composition involves arranging the elements of an image to form the most stable shape of all: the triangle. This ensures that the photograph is not only balanced, but has visual impact. ❸ As the name suggests, S-curve composition accentuates the sense of depth by arranging the subject to form the letter S. ❹ Diagonal composition is another effective way to emphasise depth. A sense of depth and breadth is produced by orienting the space or subject diagonally. ❺ Contrast composition is handy for shooting multiple vehicles. By focusing on one of the cars and altering the size of the space it occupies, it is better able to stand out as the focus of the composition.

The next concept you should get to grips with in order to give your photographs a more accomplished feel is depth of field. Depth of field is the extent of the area in front of and behind the focal point which remains in focus. Depth of field is determined by factors such as aperture value (F number), the focal length of the lens and the distance from which the photograph is taken.

The aperture of the lens is especially important. By lowering the aperture, the depth of field is increased and the full extent of the field of view is more clearly displayed. In contrast, decreasing the depth of field causes the background to appear blurred, allowing the subject to stand out better.

Since the depth of field of a telephoto lens is low, the blurred effect in front of and behind the focal point is exaggerated. If you want to make the car you are photographing stand out, remember to increase the aperture. If you want the background to appear sharper, you should reduce the aperture instead.

The use of light is also an important factor. Professional photographers not only consider basics such as composition, angle and reflections in the background and car; they also carefully select their location based on light direction and colour, and determine the optimal placement for the car within that location. In other words, whether it's morning, afternoon or evening, they take advantage of differences in light throughout the day, including its position and the angle at which it shines.

The cool, clear light of the morning, the gathering darkness of twilight and the lamp-lit glow of night-time can all conjure up very different feelings in photographs shot in the same location.

Skilful use of filters is another ingenious way to make your photographs look more accomplished. Simply by using filters in colours such as blue, red, orange and yellow to alter the hue of the car and the background, you can completely transform the style of the photograph.

A similar effect can also be achieved by experimenting with the camera's in-built white balance value. This differs from camera to camera, but common white balance presets include those calibrated for fine weather, dull weather and fluorescent lighting. These can be used to mimic the hue-changing abilities of filters. By developing a solid command of all of these techniques, you will become able to take more impressive pictures and will learn to enjoy photography even more.

[1/60 • F11 • 107mm] This image avoids exposing the foreground to light, whilst making bold use of shadows, thus accentuating the glare on the car's body.

Depth of field.

The depth of the area in front of and behind the focal point that remains in focus. Depth of field is determined by factors such as aperture (F number) and the focal length of the lens.

[1/125 • F8 • 85mm]

[1/1000 • F1.4 • 85mm]

Filter Effects

Filters, which alter the frequencies of light that enter the lens, can be used to completely transform the atmosphere of an image. They are particularly useful for giving a photo a particular mood or feel.

[1/300 • F8 • 43mm]

[1/250 • F4 • 38mm]

Capturing a Car's Character

Artistically Capturing a Moment

[1/8 • F2 • 50mm] This photograph takes great advantage of the glow emanating from the windows and the disparity between the background and the car.

[1/250s • F4 • 28mm] The car is positioned so that it becomes part of the background.

[1/15 • F2.8 • 28mm] Shooting from a low angle creates a feeling of intensity. It is also effective for making particular parts of the car stand out.

[1/125 • F2.8 • 28mm] The wind can be seen flowing off diagonally into the background.

Capturing a Car's Character

[1/500 • F8 • 43mm] The sense of stability of this composition gives the impression that the car might accelerate away at any moment.

[1/8 • F18 • 28mm] Night-time photography requires skill, but is definitely worth the challenge.

Skilfully Taking Advantage of Light and Shadow

[1/2000 • F2.8 • 200mm]

7:3 is considered the golden ratio for photographing cars. Countless photographs in catalogues and magazines are taken with this ratio.

[1/60 • F5.6 • 22mm]

Intentionally blurring the photograph generates a feeling not only of movement, but of intense speed.

Staging a Dynamic Driving Scene.

By slowing the shutter speed (top-right) you can create a sense of speed. Conversely, by increasing the shutter speed (bottom-right), both the subject and the background appear stationary. There is less intensity, but the image of the car is captured more clearly.

[1/125 • F11 • 100mm]

[1/125 • F8 • 166mm]

[1/500 • F8 • 166mm]

CHAPTER

05

Apex [The Gran Turismo® Exclusive Magazine]

Track Index

Know Your Tracks

TRACK **INDEX**

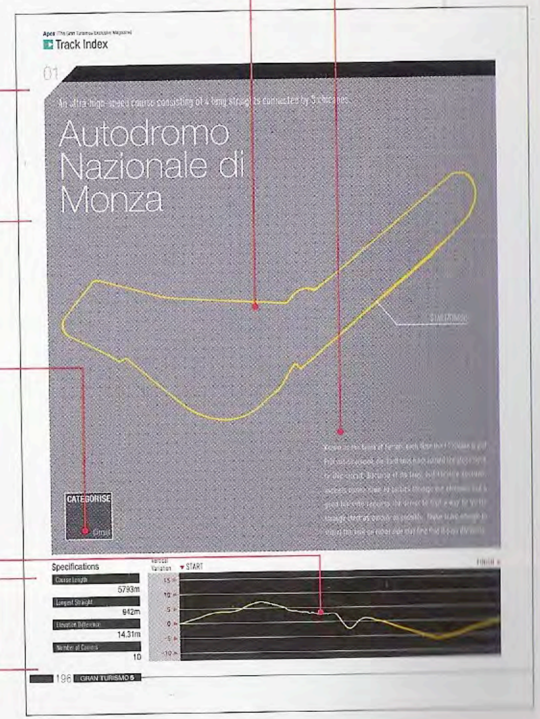
Viewing Track Data

This section introduces you to 16 of the many tracks available in Gran Turismo® 5. The selection encompasses everything from famous real-world circuits and courses set in major world city centres to grueling dirt tracks, so there's something here for everyone - no matter what your driving style.

Track layout. "START/GOAL" indicates the start/finish line.

A brief description of the name and characteristics of the track.

A brief description of the track, along with strategies for conquering it.



Specifies the track category. The four variations are World Circuits (real-world circuit), Original Circuits (Gran Turismo® original tracks), City Tracks (urban based tracks) and Snow / Dirt (unsurfaced and snow covered roads).

The elevation variation over the length of the track, with the start at 0. The scale changes depending on the overall elevation difference of the track.

Basic track data, including length, elevation difference, longest straight and number of corners.

* This list describes just some of the tracks available. For the latest news on available tracks, visit www.gran-turismo.com

01

An ultra-high-speed course consisting of 4 long straights connected by 3 chicanes.

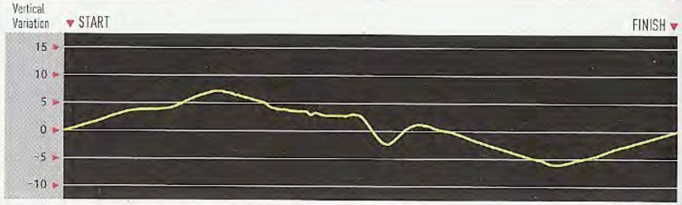
Autodromo Nazionale di Monza

Known as the home of Ferrari, each time the F1 Italian Grand Prix comes around, die-hard fans from around the globe flock to this circuit. Because of its long, full-throttle sections, success comes down to tactics through the chicanes and a good lap time requires the driver to find a way to hurtle through them as quickly as possible. Those brave enough to mount the kerb on either side may find that it pays dividends.

CATEGORISE
Circuit

Specifications

Course Length	5793m
Longest Straight	942m
Elevation Difference	14.31m
Number of Corners	10



02

A high-speed track with extremely long full-throttle sections. Beware of losing contact with the ever-undulating road surface.

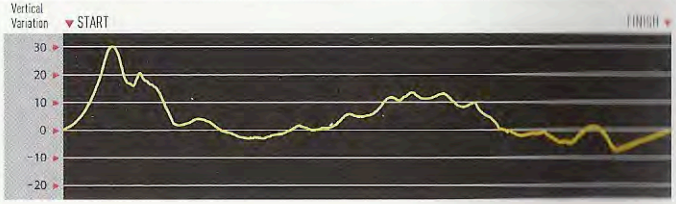
Circuit de la Sarthe

CATEGORISE
Circuit

This 13.65km circuit is famous for its length, and for being the setting for the Le Mans 24-hour race. Despite its lack of tight corners and the long full-throttle sections, a major part of the track uses public roads with a steeply undulating road surface which makes it difficult to maintain control. In addition to the most recent "2009" layout, arising from the partial modifications of 2007, there is also the choice of the "no chicane" version, where you can enjoy Hunaudières straight as it was in the age before chicanes.

Specifications

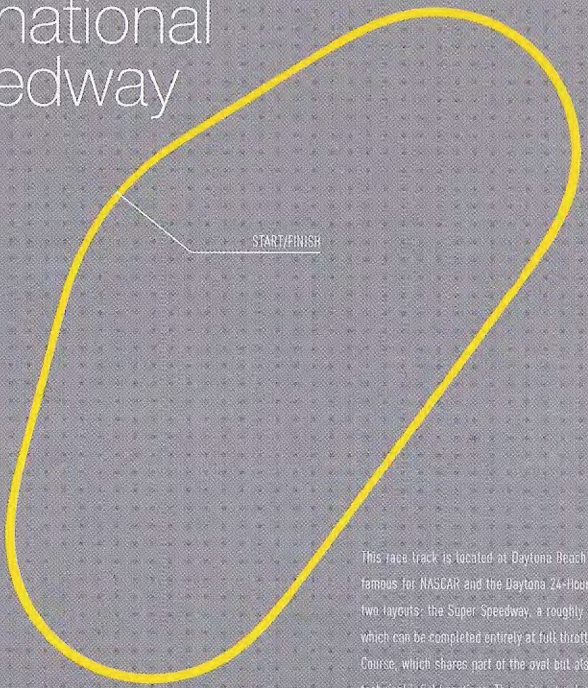
Course Length	13650m
Longest Straight	1679m
Elevation Difference	37.3m
Number of Corners	38



03

This unique track offers something for everyone, from novice to pro.

Daytona International Speedway

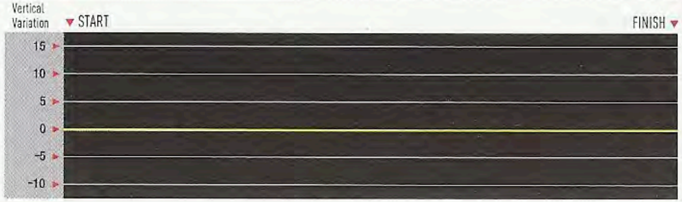


This race track is located at Daytona Beach in Florida, USA, famous for NASCAR and the Daytona 24-Hour race. There are two layouts: the Super Speedway, a roughly 4km oval circuit which can be completed entirely at full throttle, and the Road Course, which shares part of the oval but also features more technical infield sections. This unique track offers something for everyone, from novice to pro.

CATEGORISE
Circuit

Specifications

Course Length	4023m
Longest Straight	914m
Elevation Difference	0m
Number of Corners	3

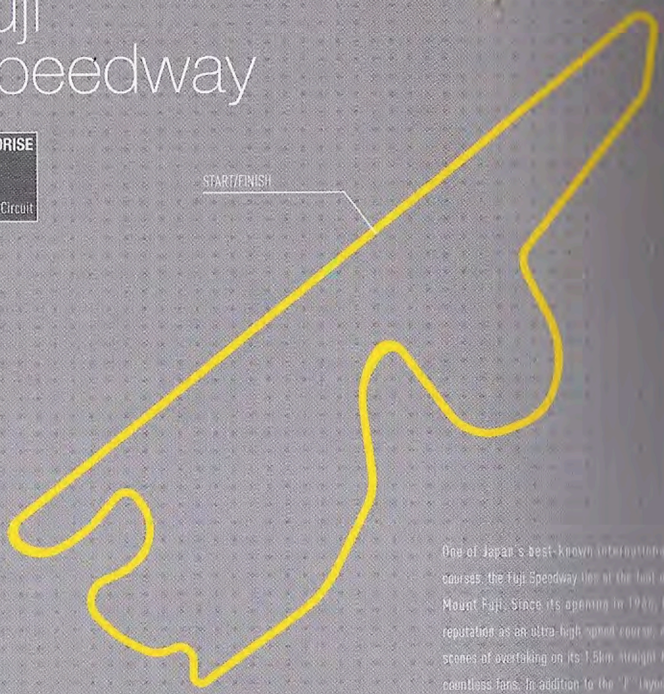


04

Japan's most well-known international racetrack, featuring a 1.5km straight.

Fuji Speedway

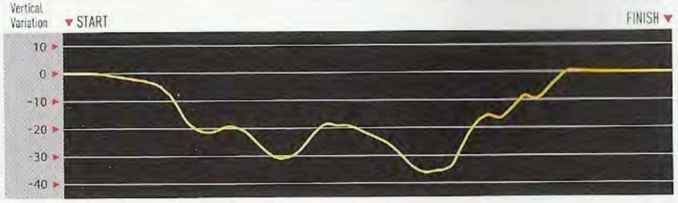
CATEGORISE
Circuit



One of Japan's best-known international motor racing courses, the Fuji Speedway lies at the foot of Japan's sacred Mount Fuji. Since its opening in 1966, it has earned a reputation as an ultra-high speed course, and the dramatic scenes of overtaking on its 1.5km straight have mesmerised countless fans. In addition to the "F" layout, with chicanes beyond the Dunlop Corner, you can also enjoy the chicaneless "GT" layout. Either way, success rests on how fast you can make it through the infield section of the latter half.

Specifications

Course Length	4563m
Longest Straight	1475m
Elevation Difference	37.0m
Number of Corners	16

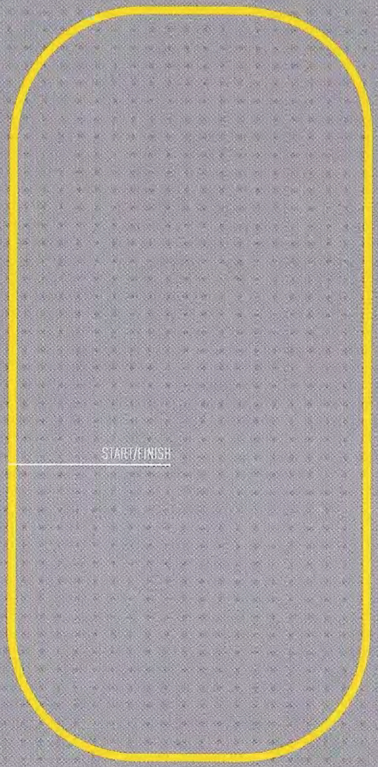


05

The legendary oval track on which American motor racing was born.

Indianapolis Motor Speedway

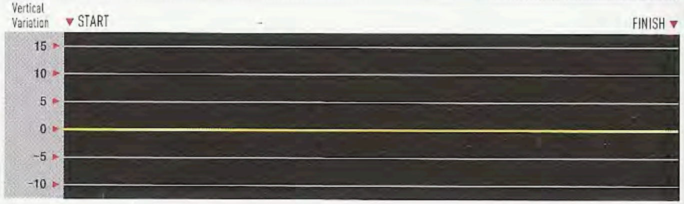
Opened in 1909, this oval track is steeped in history and has been the backdrop against which the development of America's motor racing scene has been played out. It plays host to such major events as the Indianapolis 500-Mile Race, one of the world's three biggest motor racing events. Despite its simple shape, the banks of the corners are shallow, making them demanding turns that put stress on both tyres and drivers. In addition to the Super Speedway, there is also the Road Course, with its tricky infield section.



CATEGORISE
Circuit

Specifications

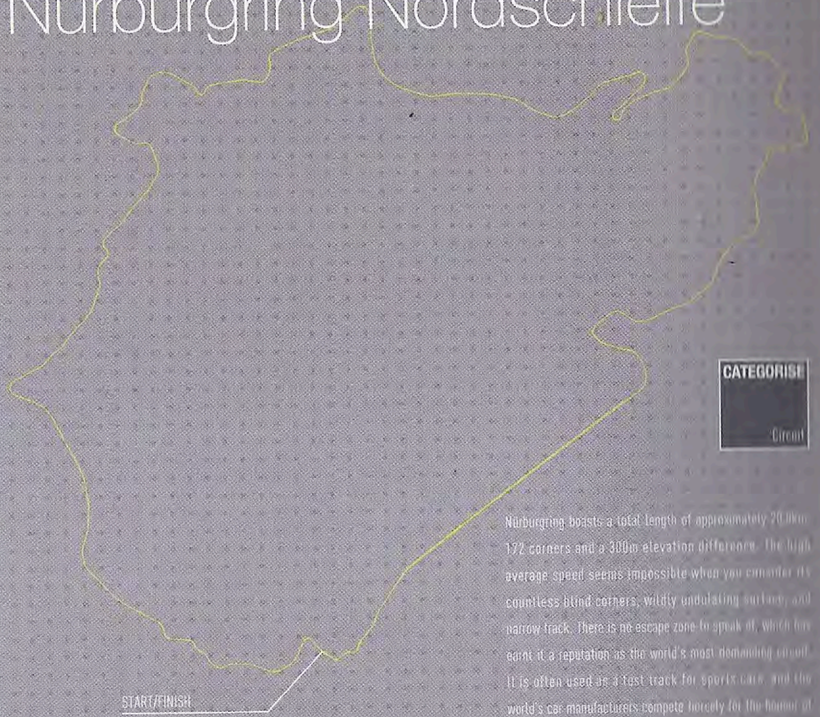
Course Length	4023m
Longest Straight	1006m
Elevation Difference	3.0m
Number of Corners	4



06

The most challenging ultra-long course in the world, with a high average speed, and terrifying uphill and downhill blind corners.

Nürburgring Nordschleife

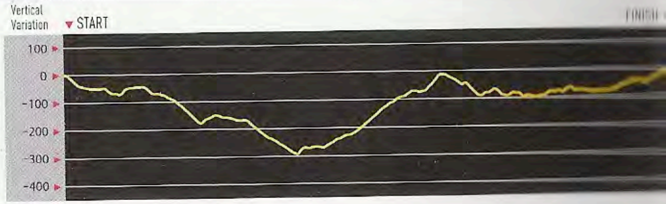


CATEGORISE
Circuit

Nürburgring boasts a total length of approximately 20.8km, 172 corners and a 300m elevation difference. The high average speed seems impossible when you consider its countless blind corners, wildly undulating surface, and narrow track. There is no escape zone to speak of, which has earnt it a reputation as the world's most demanding circuit. It is often used as a test track for sports cars, and the world's car manufacturers compete fiercely for the honour of being "Nürburgring's fastest".

Specifications

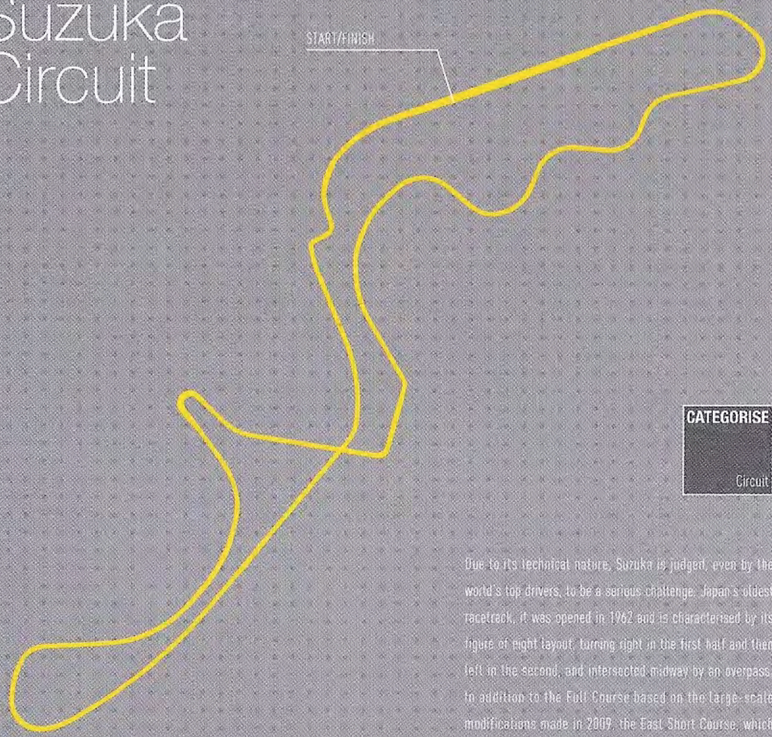
Course Length	20832m
Longest Straight	2135m
Elevation Difference	300.0m
Number of Corners	172



07

Japan's oldest classic circuit, much loved by the world's top drivers.

Suzuka Circuit

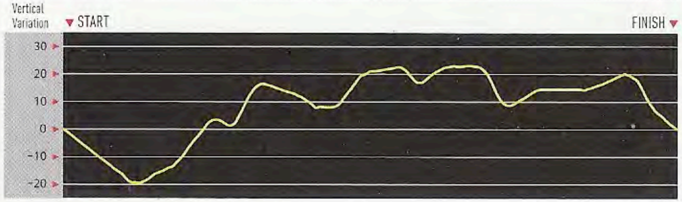


CATEGORISE
Circuit

Due to its technical nature, Suzuka is judged, even by the world's top drivers, to be a serious challenge. Japan's oldest racetrack, it was opened in 1962 and is characterised by its figure of eight layout, turning right in the first half and then left in the second, and intersected midway by an overpass. In addition to the Full Course based on the large-scale modifications made in 2009, the East Short Course, which takes a short cut from the Dunlop corner to the home straight, is also available.

Specifications

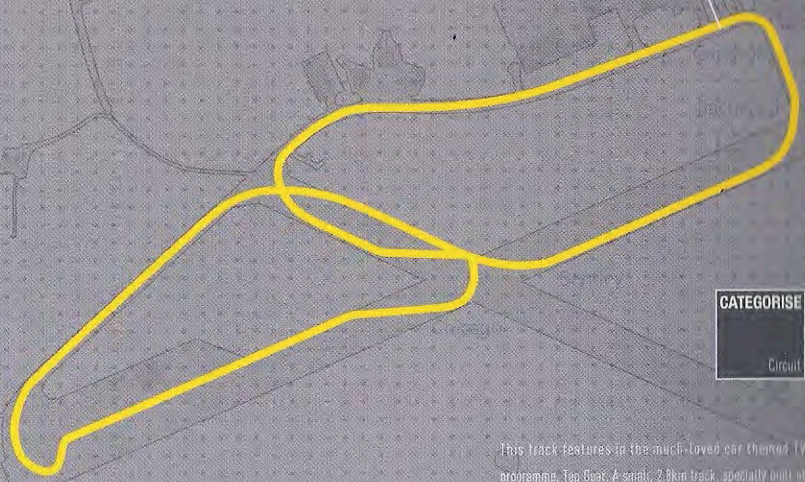
Course Length	5807m
Longest Straight	1200m
Elevation Difference	40.0m
Number of Corners	20



08

Challenge The Stig! An original track from the popular TV programme of the same name.

The Top Gear Test Track

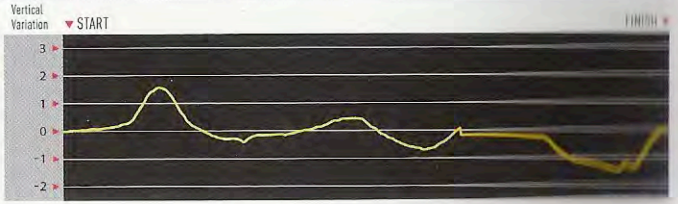


CATEGORISE
Circuit

This track features in the much-loved car themed TV programme, Top Gear. A small, 2.8km track, specially built at Dunsfold Aerodrome in Surrey, England. It is not only used in the programme to test cars but also to stage various events, such as "Star in a Reasonably Priced Car". Its layout is a simple figure of eight, which reuses a portion of the track, and overall it's more of a gymkhana circuit than a racetrack. Drivers here can look forward to challenging the ever mysterious Stig.

Specifications

Course Length	2820m
Longest Straight	350m
Elevation Difference	3.5m
Number of Corners	9

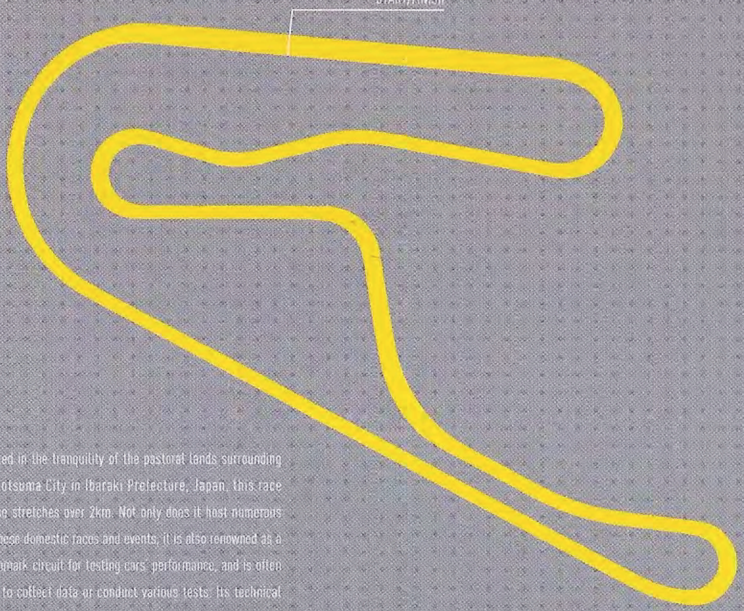


09

This Japanese benchmark circuit demands technique over power.

Tsukuba Circuit

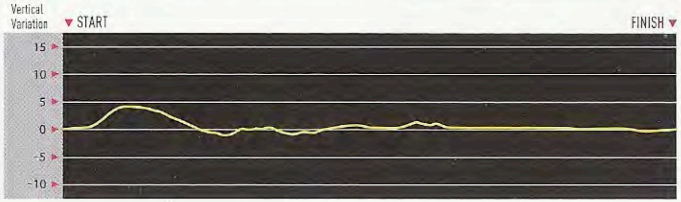
CATEGORISE
Circuit



Located in the tranquility of the pastoral lands surrounding Shimotsuma City in Ibaraki Prefecture, Japan, this race course stretches over 2km. Not only does it host numerous Japanese domestic races and events, it is also renowned as a benchmark circuit for testing cars' performance, and is often used to collect data or conduct various tests. Its technical layout involves two straights linked by mid- to low-speed corners, and its compactness is said to reduce the impact of power differences on lap times.

Specifications

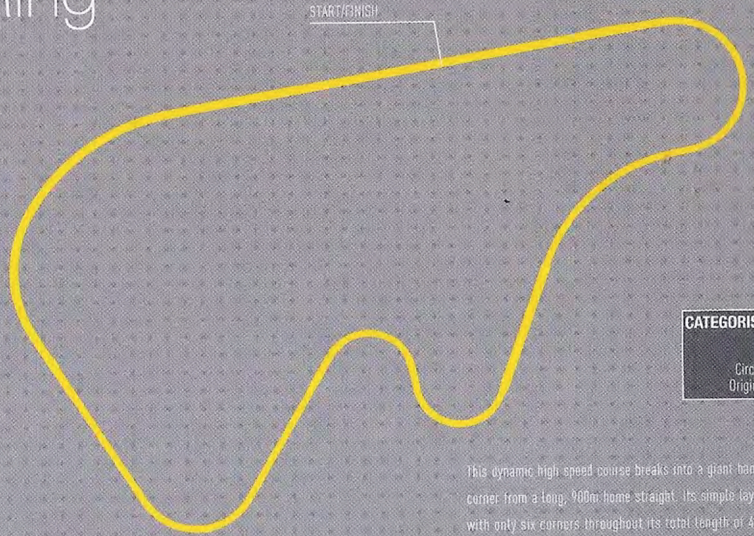
Course Length	2045m
Longest Straight	445m
Elevation Difference	5.3m
Number of Corners	8



10

Use the course's width to accelerate quickly and generate escape velocity.

High Speed Ring

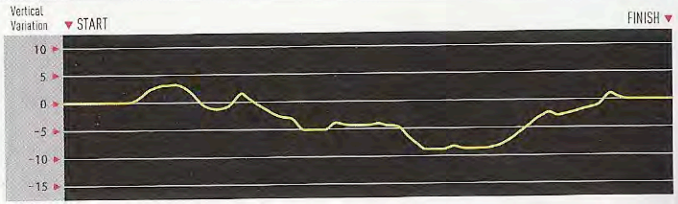


CATEGORISE
Circuit
Original

This dynamic high speed course breaks into a giant banked corner from a long, 900m home straight. Its simple layout, with only six corners throughout its total length of 4km, belies the capacity of each corner's escape velocity to drastically affect lap times. Particularly striking are the S-corner, which appears midway, just before the full-throttle section, and the final corner. Making effective use of the track's width to accelerate quickly and generate escape velocity is key.

Specifications

Course Length	4000m
Longest Straight	900m
Elevation Difference	8.5m
Number of Corners	6



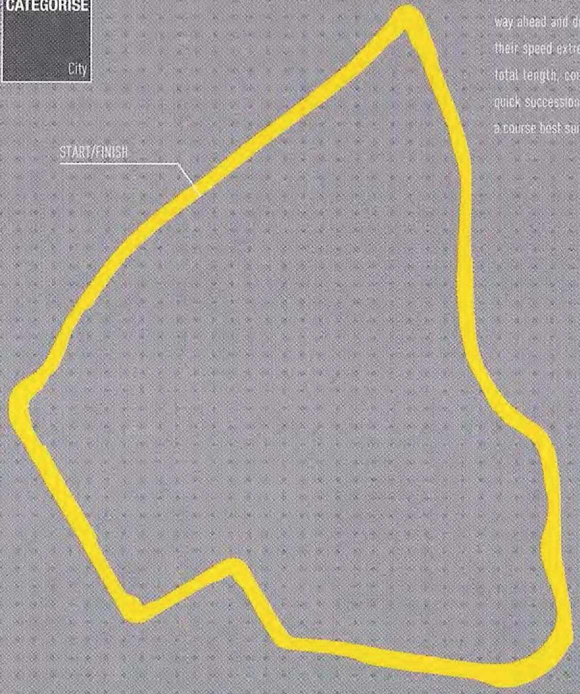
11

Focus on maintaining a good racing line and controlling your speed to overcome the blind corners.

London

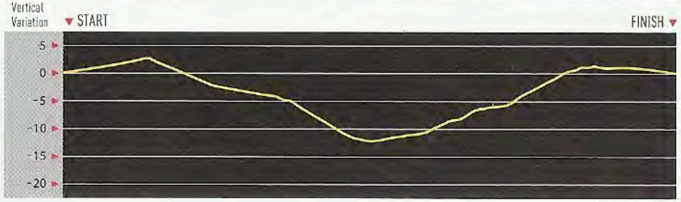
CATEGORISE
City

With a total length of 2km, this street course circles tourist attractions such as Piccadilly Circus and Trafalgar Square. Since all of the corners are blind, it is impossible to see the way ahead and drivers must take the perfect line and control their speed extremely accurately. Indeed, although short in total length, corners of various different speeds appear in quick succession, making it more involved than it looks. It is a course best suited to compact cars with low-grip tyres.



Specifications

Course Length	1921m
Longest Straight	320m
Elevation Difference	14.5m
Number of Corners	8

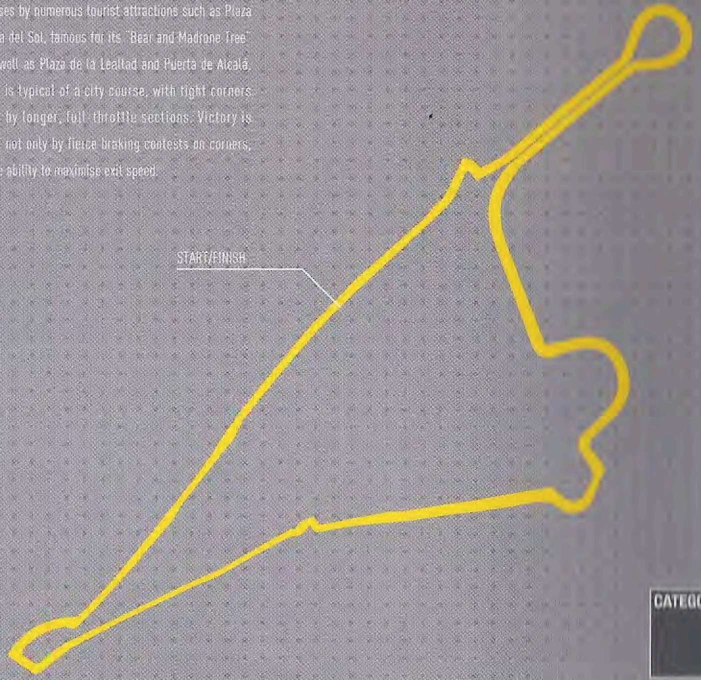


12

A 3.4km street track set in the historic quarter of Madrid.

Madrid

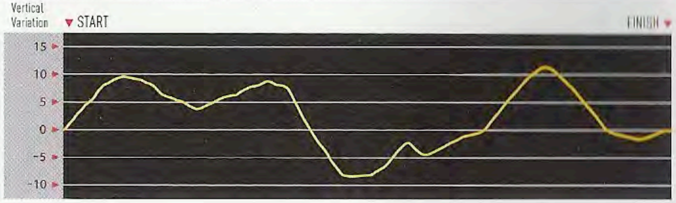
Set in Madrid, with Calle de Alcalá as its home straight, this course passes by numerous tourist attractions such as Plaza de la Puerta del Sol, famous for its "Bear and Madrone Tree" statue, as well as Plaza de la Lealtad and Puerta de Alcalá. The layout is typical of a city course, with tight corners connected by longer, full-throttle sections. Victory is determined not only by fierce braking contests on corners, but also the ability to maximise exit speed.



CATEGORISE
City

Specifications

Course Length	3400m
Longest Straight	820m
Elevation Difference	17.7m
Number of Corners	15

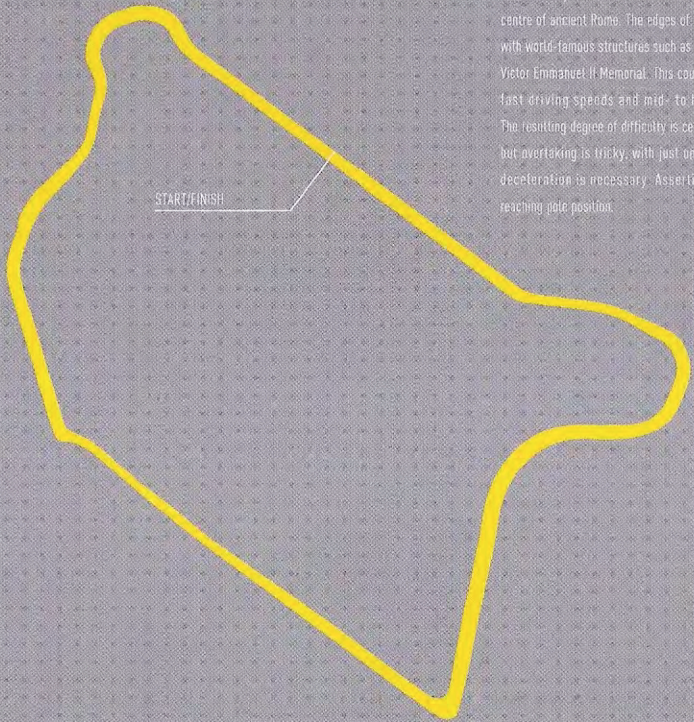


13

A high-speed course characterised by medium- to high-speed corners and tough overtaking conditions.

Rome

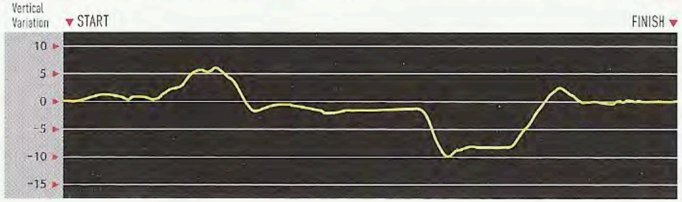
A 3.5km city course which circles the Roman Forum, the centre of ancient Rome. The edges of the track are brimming with world-famous structures such as the Colosseum and the Victor Emmanuel II Memorial. This course is characterised by fast driving speeds and mid- to high-speed corners. The resulting degree of difficulty is certainly on the low side, but overtaking is tricky, with just one point where sudden deceleration is necessary. Assertiveness is the key to reaching pole position.



CATEGORISE
City

Specifications

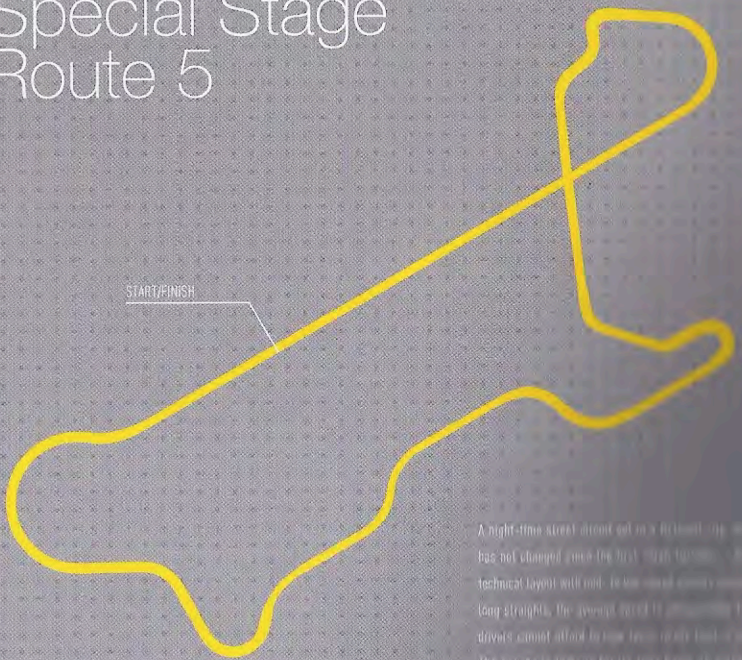
Course Length	3473m
Longest Straight	650m
Elevation Difference	17.93m
Number of Corners	7



14

A night stage lit by the glow of streetlights. Make good use of the long straight!

Special Stage Route 5

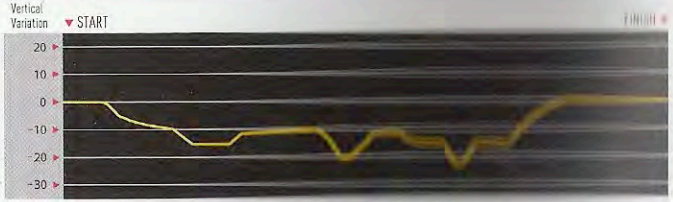


A night-time street [illegible] has not changed [illegible] technical layout with mid- [illegible] long straights, the [illegible] drivers cannot afford [illegible] The course is famous for [illegible] stretches out for [illegible] exaggeration to say that [illegible] the final corner [illegible] beyond it.

CATEGORISE
City

Specifications

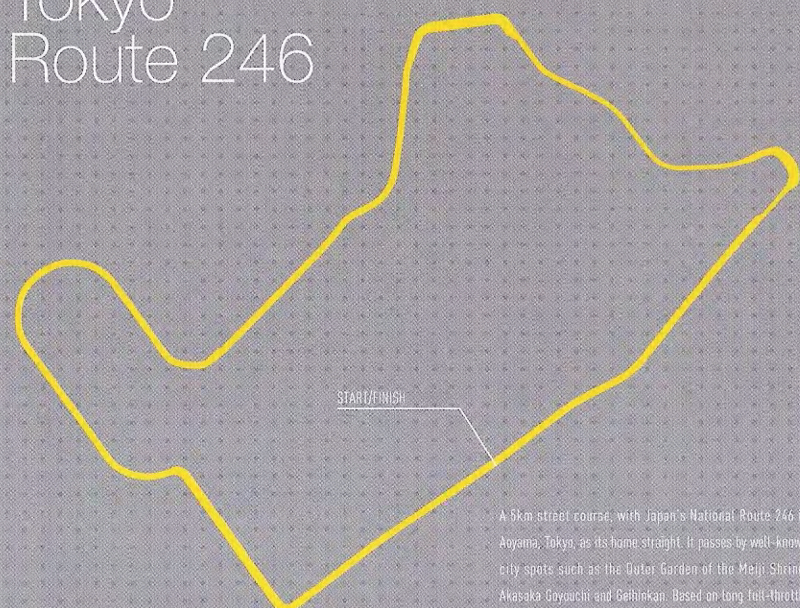
Course Length	3787m
Longest Straight	1001m
Elevation Difference	21.2m
Number of Corners	16



15

A street course where mid- to high-speed corners lie in wait beyond a long full-throttle section.

Tokyo Route 246

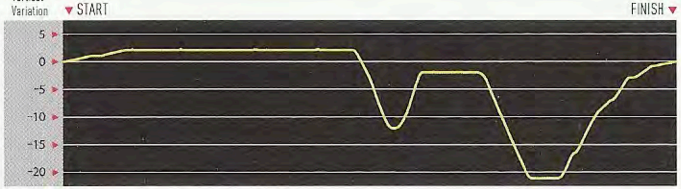


A 5km street course, with Japan's National Route 246 in Aoyama, Tokyo, as its home straight. It passes by well-known city spots such as the Outer Garden of the Meiji Shrine, Akasaka Goyouchi and Geihinkan. Based on long full-throttle sections and mid- to high-speed corners, the average speed is high. Moreover, even though the road is wide, being a city course, there are no escape zones, and drivers are required to exercise precise control. Overtaking is difficult, with the long home straight and the approach to the first corner constituting the only real passing opportunities.

CATEGORISE
City

Specifications

Course Length	5117m
Longest Straight	806m
Elevation Difference	23.2m
Number of Corners	15



16

Don't be fooled by the majestic landscape, this mountainous stage hides some tricky corners.

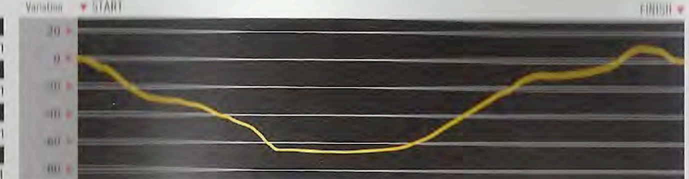
Eiger Nordwand

This mountainous course is set on hilly terrain in the vicinity of the Kleine Scheidegg at the base of Eiger Nordwand, one of the world's three biggest north faces. Despite the sprawling, majestic landscape, tight, undulating corners appear in quick succession, resulting in a fiendish level of difficulty. Moreover, the first half is downhill while the second half is uphill, and since the frequency of corners is inconsistent, it is difficult to establish momentum, lending this course a characteristically tricky flavour. One thing for certain on this track is that cars must rely more on turning ability than power.

CATEGORISE

Specifications

Course Length	2436m
Longest Straight	250m
Elevation Difference	75.0m
Number of Corners	11



Facts and Figures

Technical
(Number of Corners)

1. 172 (Nürburgring Nordschleife) 2. 38 (Circuit de la Sarthe) 3. 20 (Suzuka Circuit)

Long
(Course Length)

1. 20832m (Nürburgring Nordschleife) 2. 13650m (Circuit de la Sarthe) 3. 5807m (Suzuka Circuit)

Dynamic
(Elevation Difference)

1. 300m (Nürburgring Nordschleife) 2. 40.0m (Suzuka Circuit) 3. 37.3m (Circuit de la Sarthe)

High-speed
(Length of Straights)

1. 2135m (Nürburgring Nordschleife) 2. 1679m (Circuit de la Sarthe) 3. 1475m (Fuji Speedway)

* These top 3s are based only on courses appearing in this list.

G R A N T U R I S M O 5

POLYPHONY DIGITAL

You
see the corner
closing in rapidly as the scenery
blurs by at blinding speed.
Taking your foot off of the throttle, you
slam on the brakes. The G-force from the
deceleration immediately dominates your
senses and the tyres scream out as they
fight against the road surface. The seatbelt
digs into your flesh. The tach needle shoots
up at every shift downward. Letting off the
brakes slightly, you turn the wheel gradually
but with confidence. The G's from the
deceleration lessen while horizontal G's take
over, ramming your body against the side
of the bucket seat. You're aiming for just
one sweet spot in the corner. It's the point
where centrifugal and cornering forces reach
their equilibrium, where they are all at once
replaced with acceleration.

"APEX" - The invisible vertex of a corner,
a place where the fastest lap times
are recorded.

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